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GENERAL MEETING.

Held in the Apartments of the Geological Society, April 7th, 1899.

Mr. R. H. Scott, M.A., F.R.S., Past-President, in the Chair.

Thirteen Members and one Visitor were present.

The following papers were read:—

On Langbeinite from the Mayo Salt Mines in the Punjab: by Mr. F. R. Mallet, F.G.S.

On the Use and Advantages of a Three-Circle Goniometer: by Mr. G. F. Herbert Smith, B.A.

On a mass of meteoric iron found in Patagonia: by Mr. L. Fletcher, M.A., F.R.S.

Mr. Fletcher exhibited an etched slice of the Patagonian iron, and also a plaster-cast of the mass lent by Dr. Moreno, who first recognised the meteoric origin of the specimen.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, June 20th, 1899.

Professor A. H. Church, M.A., F.R.S., President, in the Chair.

Mr. William Pollard, M.A., Ph.D. was elected an Ordinary Member of the Society.

Resolved to nominate Mr. Beale, The Earl of Berkeley, Mr. Hutchinson, and Mr. Spencer to replace the four retiring Members of Council (Gen. McMahon, Mr. Barlow, Professor Miers and Mr. Pope).

GENERAL MEETING.

Held in the Apartments of the Geological Society, June 20th, 1899.

Prof. A. H. Church, M.A. F.R.S. President, in the Chair.

Seventeen Members were present.

The following papers were read :—

1. On the Constitution of the Mineral Arsenates and Phosphates.

Part II. Plumbogummite and allied minerals : by Mr. E. G. Hartley, B.A.

2. Note on Plumbogummite: by Professor H. A. Miers, M.A., F.R.S.

3. On a Pyroxene from South Africa : by Mr. H. L. Bowman, B.A., F.C.S.

4. On the Chemical Constitution of Tetrahedrite : by Mr. G. T. Prior, M.A., F.G.S., and Mr. L. J. Spencer, M.A., F.G.S.

5. On a constituent of the meteoric iron of Youndegin, Western Australia: by Mr. L. Fletcher, M.A. F.R.S.

6. On the meteoric stones which fell at Mount Zomba, British Central Africa, on January 25th, 1899 : by Mr. L. Fletcher, M.A., F.R.S.

Mr. Bowman exhibited specimens in illustration of his paper and also a twin-crystal of sapphire from Cashmere : Mr. Fletcher showed specimens of tænite isolated from the Youndegin meteorite.

THE MINERALOGICAL MAGAZINE

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No. 56. OCTOBER, 1899. Vol. XII.

On a new mode of occurrence of Ruby in North Carolina.

By Prof. J. W. Judd, C.B., LL.D., F.R.S., V.P.G.S., and

W. E. Hidden, F.G.S.

With Crystallographic Notes by Dr. J. H. Pratt.

[Read Jan. 31st, 1899.]

PARTS of the State of North Carolina, with adjoining areas in South Carolina and Georgia, have long been known to mineralogists and geologists as among the most interesting of corundum localities; and the researches of the late Dr. Genth, Col. Joseph Willcox, Mr. J. Volney Lewis and many other authors have done much to make clear the mode of occurrence and associations of corundum in this area and in the great corundiferous belt stretching along the line of the Appalachian crystalline area from Alabama in the south to Maine in the north. Quite recently Dr. J. H. Pratt has published a very interesting and admirable discussion of "The origin of the Corundum associated with the Peridotites of North Carolina."[1]

But of the existence in any part of this area, or indeed in any part of the continent of America, of the red transparent variety of the mineral, which the term Ruby is properly restricted, there appears to have

[1] *Amer. Journ. Sci.* 4th Ser. Vol. VI. 1898, p. 49.

been no knowledge till about 15 years ago (1884). Nor has there been, as yet, any notice published of the discovery in any scientific journal or magazine, unless we except the brief mention made in the Annual Statistical volumes entitled *Mineral Resources of the United States*, published under the auspices of the U.S. Geological Survey.[1]

Some few additional notes upon this interesting occurrence have been published, including press notices, but nothing of a strictly scientific character. We may state that one of us has during the past five years frequently visited the scene of this discovery, and that from time to time we have conjointly examined many of the cut specimens and natural crystals of the rubies from the Cowee district of North Carolina, and that in our opinion their beauty and colour appear to be in no way inferior to those from the Mogok district of Burma.

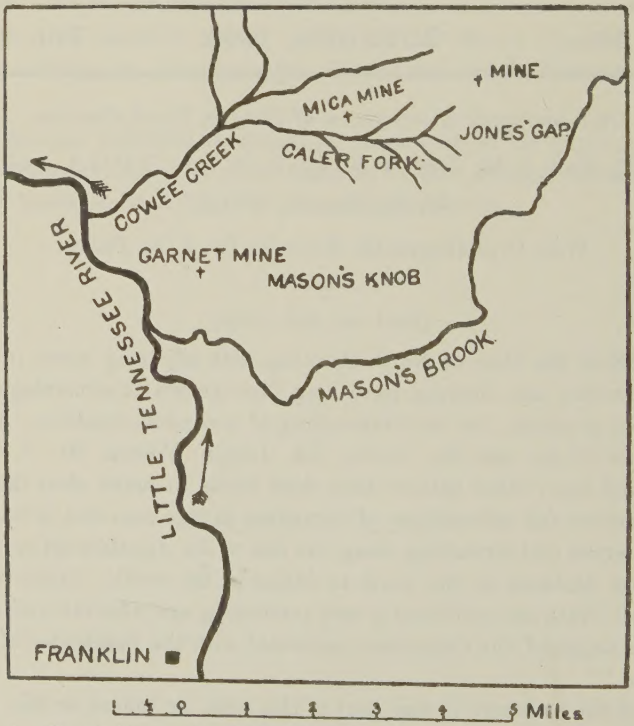

Fig. 1.—Sketch Map of the district in which Ruby and Rhodolite are found.

[1] 15th Annual Report, 1893–94, U.S. Geol. Survey, Volume on *Mineral Resources of the United States* (Washington, 1894), p. 693.
Ibid. 16th Annual Report, Part IV. p. 599.
Ibid. 17th Annual Report, Part III. p. 905.

As the material in which these rubies were found appeared so strikingly similar to the alluvium and gravel in which the Burma rubies are obtained, it at one time seemed highly probable that when the thick masses of superficial and detrital material could be sunk through, the rock in which the rubies would be found *in situ* would prove to be a limestone like that of Burma. This expectation was strengthened by the finding in the gravels of corundum crystals of similar form, with almost precisely the same association of minerals as occurs in Burma.

The district in which these interesting discoveries have been made is situated in the State of North Carolina and in the County of Macon, rather more than 20 miles from the borders of Georgia. Some five or six miles below the town of Franklin the Little Tennessee River receives on its right or eastern side two affluents, the Cowee Creek with its tributary the Caler Fork, and the Mason Branch. It is the tract between these two brooks, some 10 square miles in area, which has proved to be of such exceptional mineralogical interest, and has yielded a very large number of remarkable species and varieties of minerals.

The bottoms of the valleys of this mountain district are about 2,500 feet above the sea-level, and the various hills ("knobs") in and immediately around it rise to the height of from 3,000 to 3,500 feet; but at no great distance to the west there occurs much higher ground (the Nantahaleh Mountains) up to 5,000 and 5,500 feet.

In 1896 the district was visited and examined by Mr. C. Barrington Brown, who had made the examination for the British Government of the well-known ruby district of Mogok in Burma. He found that the country was one of gneissose rocks, the gneiss often containing garnets and corundum,[1] not of gem quality, and that this mass of gneissose rocks is probably traversed, like that of Burma, by great dykes of pegmatite and more basic rocks, for blocks of these materials are abundantly scattered through the gravels of the district.

Garnets are so abundant in some of the rocks of the district that mines have been opened to work the rocks for abrasive materials. In some of the pegmatites the crystals of muscovite are so well developed that several "mica mines" have been opened. There are other mines which have been worked for copper with some prospects of success; while, as we shall see in the sequel, gold, monazite, and sperrylite (the rare

[1] The corundum in these gneissose rocks usually occurs in long hexagonal prisms with basal planes, but no other forms, and the mineral nearly always exhibits purplish tints.

arsenide of platinum) have been obtained in the alluvial deposits which are so extensively present in this region.

Although only a few miles away from Corundum Hill, Buck Creek, Ellijay, and other famous corundum localities, where, as shown by Lewis, Pratt, and other authors, corundum is found in the intrusive dunites, near their junction with the crystalline schists of the district, *no* olivine rocks, or serpentines derived from them, have been found in the immediate neighbourhood of the new ruby locality.

Neither have limestone rocks been found in close proximity to the alluvia containing these fine rubies. In fact, the nearest point at which any limestone bands have been found is about eight miles away. Here the bands consist of a "calciphyre," not unlike some of those found in Burma, and, like them, containing many silicates, such as wollastonite, scapolite, pyroxenes, hornblendes, biotite, &c., with graphite, pyrrhotite, and many other minerals.

When the alluvium and the gravels below them (the latter being from 2 to 10 feet in thickness) are penetrated, they are often found to rest on a soft rock known to American petrologists as "saprolite," which is the result of the weathering in place of basic silicate rocks. This "saprolitic" rock can often be pierced to considerable depths, without the undecomposed rocks from which it has been derived being reached.

Washing and microscopic examination of the saprolitic material shows that it is largely made up of scales of various hydrous silicates, among which damourite and other hydrous micas, with margarites and other clintonites, are very conspicuous. The unaltered minerals present consist of fibrolite, staurolite, and some other silicates, with menaccanite, rutile, monazite, spinel, and considerable quantities of garnet (including the rhodolite variety) and corundum (of various shapes and tints), and minute quantities of gold and sperrylite.

The trial shafts and gravel-washing operations which have been undertaken in this district, with a view to discover the extent and nature of the valuable minerals, have shown that at depths of 35 feet and upwards the saprolitic rock includes fragments, and is seen to pass into various basic rocks. These include hornblende-eclogite (garnet-amphibolite of some authors), amphibolite, and a basic hornblendic gneiss containing labradorite and perhaps anorthite. The full description of these rocks is deferred until the exploration now going on shall have more fully displayed their relations in the field, and have enabled more satisfactory and less altered specimens to be obtained. It is as yet uncertain whether these rocks occur as dykes or as alternating interfoliated masses in the crystalline series.

The great band of basic and garnet-bearing rocks, in the decomposed materials derived from which are found the rubies, is traversed by a remarkable series of slickensides. Four parallel slides have been exposed at one place in the workings, the direction being generally N. 75° E. Continuous slickensides of 70 feet in length, and of unknown depth, can be seen, and, with some interruptions, they can be traced for several hundreds of feet east and west. It is probably the breaking up of these rock-masses by faulting, leading to the ready influx of water (which so readily attacks the basic silicates of which the rock is composed), that has led to their reduction to the saprolitic condition.

Scattered through the saprolitic material are nuclei of eclogite and amphibolite, which have to some extent escaped disintegration, and in the centre of the mass lenticles of pure hornblende rock are found. In one place one of these lenticles of hornblende rock is nearly a rod in width, and in nearly all cases the saprolite adjoining these lenticles of hornblende rock is seen to contain, very abundantly, either corundum or more commonly the pseudomorphs after corundum.

The corundum occurring in these rocks varies in colour from ruby red through various shades of pink to white and nearly colourless varieties. Many of the red crystals exhibit the beautiful so-called pigeon's-blood tint, which is so much admired in the gems from Burma, and the colours seen in the Cowee-Creek stones with the dichroscope are almost identical with those exhibited by the stones from Burma. As at Mogok, Sagyin, and other Burmese localities, the rubies of very fine tint are mingled with others of lighter or darker shades, and with varieties which exhibit more or less of a purplish tint mingled with the red.

The Cowee-Creek rubies very frequently contain inclusions of various kinds. Sometimes these are extremely minute ("silk" of jewellers), and give rise to a cloudiness ("sheen") in the polished gems; at other times minute reniform masses of clear red rutile and black menaccanite occur, and mar their beauty. The included crystals of garnet, to be hereafter more particularly noticed, do not greatly destroy the transparency or impair the fine character of the stones. Some specimens have been found, however, from which gems of fair size could be cut, quite free from inclusions and of fine colour and transparency.

The clearest crystals of the Cowee-Creek rubies nearly always show the tabular habit which Lagorio regards as characteristic of the varieties of corundum that have separated from an igneous magma. Indeed, so common is this form, that any long prismatic crystals found with them may be suspected of having been derived from the surrounding gneisses,

in which such forms occur sometimes abundantly. The most common combination of forms is that shown in the accompanying drawing, which has been made by Professor S. L. Penfield, of the Sheffield Scientific School, Yale University.

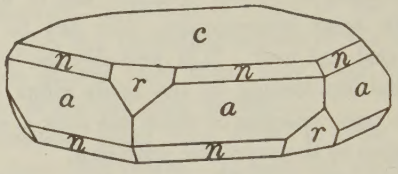

Fig. 2.

Common form of Corundum Crystals at Cowee-Creek.

In an appendix to this paper Dr. Pratt has drawn and described some of the chief types of corundum crystals obtained in the Cowee district, and it will be found interesting to compare these with the combinations of forms which the same author has described as occurring at Yogo Gulch, Montana,[1] and which Dr. Max Bauer has described from Burma.[2]

The corundum crystals, whether ruby-red or pink in colour, occur in "nests" and "bands," and also in what appear to have once been empty spaces in the rocks, either amphibolite, or eclogite, or hornblendic gneiss. The spaces, when the corundum is pale-coloured, appear to have been filled up with felspathic material; but when the corundum is of a ruby-red colour, the surrounding space is filled up with chloritic material.

Corundum is not, however, confined wholly to these bands, which were once druse-like cavities in the rock, but it often happens that the mineral, sometimes red and transparent, is found in the midst of the rock.

One respect in which the corundum of Cowee-Creek resembles that of Burma is in the readiness with which it seems to have undergone pseudomorphous change by hydration followed by combination of the resulting diaspore with surrounding silicates. The pseudomorphous material often retains the shape and occupies the place where crystals of corundum were originally firmly embedded in the hard matrix. Often only a thin flake of corundum remains in the midst of a mass of alteration products to tell the character and colour of what was once a large crystal.

It is surprising to see the positive evidence of the former existence of hundreds of pounds weight of ruby and other varieties of corundum, where, to-day, only a few ounces of fragments or flakes remain.

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[1] *Amer. Journ. Sci.* 4th Ser. Vol. IV. (1897), pp. 424–428.

[2] *Neues Jahrb. für Min.* &c. 1896, Bd. II. pp. 197–238.

The most notable of the minerals associated with the rubies and other forms of corundum at Cowee-Creek is garnet, and this garnet is remarkable for its colour and beauty as a gem-stone. The colour is unlike that either of pyrope or almandine, and lacks that depth and intensity which usually makes garnets such dark-looking stones, especially by artificial light. These garnets, on the contrary, have a peculiar and very beautiful tint, combined with a transparency and brilliancy which is more striking in artificial light than in ordinary daylight. From the resemblance of its colour (a pale rosy tint inclining to purple) to that of certain roses and rhododendrons, this variety of garnet has received the name of "rhodolite."[1]

The rhodolite usually occurs in water-worn fragments, mixed with corundum and the other minerals found in the "saprolitic" rock and in the gravels of the district. Only minute crystals, occurring as inclusions, have as yet been found, and these are sometimes rhombic-dodecahedra and at other times trapezohedra (icositetrahedra). The garnets show the same tendency to alteration as the corundum, and pseudomorphs of the mineral abound, as is the case in Burma.

The association of rubies and rhodolite in this district is not only proved by their constant occurrence together in the saprolitic material and in the gravels, but we find indisputable evidence that the garnets have crystallised first, and that the corundum has solidified afterwards, and has enclosed the garnets partially or entirely in its crystals. Some

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[1] The rhodolite of the Cowee-Creek and Mason's Branch district has been recently carefully studied by Dr. Pratt in conjunction with one of us.

"On Rhodolite, a new variety of Garnet," by W. E. Hidden and J. H. Pratt. *Amer. Journ. Sci.* 4th Ser. Vol. V. (1898), pp. 294–296. [Abstr. *Min. Mag.* xii, 133.]

Analysis shows that it has the following composition:—

Silica	41·59
Alumina	23·13
Ferric Oxide	1·90
Ferrous Oxide	15·55
Magnesia	17·23
Lime	·92
	100·32

This analysis corresponds, almost exactly, to a combination of two molecules of the magnesium-aluminium garnet (pyrope) with one molecule of a ferrous iron-aluminium garnet (almandine). There is considerable variation in the tint of rhodolite, the approach being sometimes towards the pyrope colours, at others towards the almandine. Probably the proportion of the two molecules is by no means constant. In spite of the preponderance of the pyrope molecule, as shown by analysis, an examination of the absorption bands of rhodolite, which was kindly made for us by Professor Church, F.R.S., shows that it gives the same characteristic spectrum as is found in almandine.

of the ruby crystals bear impressions, of which a mould can be taken in wax, and these impressions give with a goniometer the angles of the rhombic-dodecahedron or the trapezohedron. In some cases clear crystals of ruby corundum have been broken open, and minute garnets actually taken out of the middle of them. In other cases fractured surfaces of the basic rocks show corundum surrounding and enclosing garnet crystals, while in other cases cut gems of ruby can be seen to have in their midst a garnet crystal.

So far as our experience goes, this enclosure of garnet by corundum is peculiar to this special Cowee district, and serves to distinguish the corundum found in it from that occurring in any of the tracts where the mineral occurs in peridotites (dunite, &c.), or at the junction of peridotites with the crystalline schists.

This remarkable association of garnet and corundum is well illustrated by a drawing (Fig. 3) made upon the spot by one of us from a specimen that was of too friable a character to bear removal intact. Although the sketch is to a certain extent ideal, it faithfully represents the undoubted relations of the garnets and corundum as seen in one very interesting specimen.

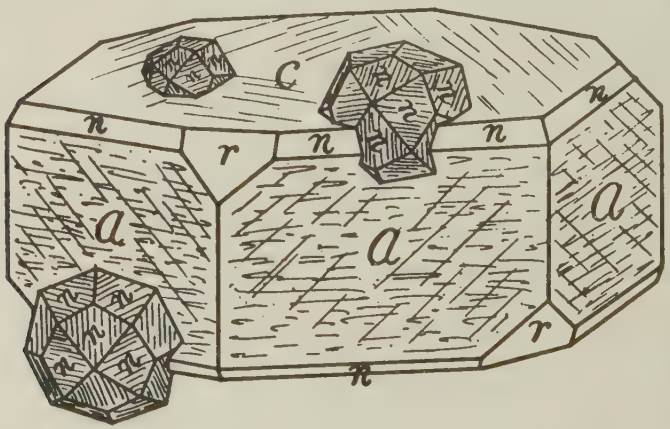

Fig. 3.

Corundum enclosing crystals of Garnet.

Specimens are occasionally found in the district which appear to be pseudomorphs of quartz after dodecahedral garnets.

Spinel, which is so constantly associated with the corundum (ruby) of Burma, is rare in the American locality. The fine red spinels, so similar

in tint to the rubies themselves, and so conspicuous in the Burma localities, appear to be entirely wanting in the North-Carolina area. Three varieties of spinel, namely, picotite, gahnite, and chromite (the last being rare), have been found both in the alluvial deposits and *in situ* in the basic rocks.

Of minerals specially characteristic of materials formed by contact metamorphism, the following have been found:—Sillimanite (fibrolite), cyanite, staurolite (often very clear and gem-like in character), and cordierite (or iolite, colourless and without dichroism).

The chief ferro-magnesian silicates are hornblende (a variety rich in soda) and bronzite (in clear transparent masses suitable for gems).

Among the accompanying minerals are zircon (with the variety cyrtolite), monazite (the macroscopic brown and green varieties appear to be rare, but a minute brilliant yellow granular variety with only 0·03 per cent. of thoria abounds), rutile and menaccanite.

Among metallic minerals the chief are pyrite, chalcopyrite, nickeliferous pyrrhotite, blende, sperrylite, and gold.[1]

Conclusions.

Corundum has now been shown to occur in North Carolina and the adjoining States in three different forms: —

(1) In the ordinary crystalline schists of the district, long prismatic crystals, usually of gray, pink and blue tints, occur.

(2) In the peridotites (dunites, &c.), intrusive in the crystalline schists, and especially in and near the zones of contact, crystals, some of very great size, and of great variety of colour, but seldom or never clear and translucent, are found.

(3) In certain garnet-bearing basic rocks at Cowee-Creek, small tabular and short prismatic crystals are abundant, and these very frequently exhibit the transparency and colour of the true ruby.

Dr. Pratt, in his recent discussion on the second of these modes of occurrence of corundum, has shown grounds for concluding that the alumina of the corundum was in these cases originally dissolved in the fused basic magma of the peridotites, and that crystals of corundum separated from that magma in the manner which has been illustrated by the interesting experiments of Morozewicz.[2]

[1] For fuller details concerning these accompanying minerals with analyses consult a paper "On the Associated Minerals of Rhodolite," by W. E. Hidden and J. H. Pratt. *Amer. Journ. Sci.* 4th Ser. Vol. VI. (1898), pp. 463–468.

[2] *Zeits. Kryst.* Vol. XXIV. (1895), p. 281, and *Tscherm. Min. und Petrog. Mitt.* (*Neue Folge*), Vol. XVIII. (1898), pp. 1–90, 105–240.

The tabular form of the crystals of corundum has been shown by Lagorio[1] in his well-known memoir on the subject to be characteristic of corundum found in igneous rocks. And this conclusion has been supported by the researches of Professor L. V. Pirsson and Dr. Pratt.[2]

If we compare the forms figured by Dr. Pratt in the appendix to this paper with those described by him from Yogo Gulch, the resemblance will be seen to be very striking. But it may at first sight appear that it is impossible to ascribe an igneous origin to corundum enclosing a mineral with so much lower a fusing point as that of garnet.

A little consideration will, however, show that this objection has little validity. The temperature at which alumina is dissolved in a mixture of silicates has no necessary connection with the fusing point of alumina itself. That the magma from which these basic rocks consolidated was fluid at a temperature lower than the fusing point of the garnets, or at all events that the rock was in a state of aqueo-igneous fusion at a lower temperature, is evidenced by the condition of the beautifully crystallised garnets scattered through the basic rocks. At such temperatures, according to the experiments of Morozewicz, alumina may be largely dissolved in the basic fluid magma, and may slowly crystallise out from it. In this way we may conceive of the garnets being enclosed in a later formed corundum.

There are many points of resemblance between the association of minerals and the forms of crystallisation of the Cowee-Creek rubies and those of Burma. This will become apparent if we compare the figures now published with those given by Prof. Max Bauer of the Burma rubies.[3]

In considering the association of minerals described by Prof. Max Bauer in his paper it should be remembered that the material on which that author worked came almost entirely from Sagyin, while those described by Mr. Barrington Brown and one of us were derived from the Mogok district, nearly 60 miles away. There is reason for concluding that the associations of minerals in these two districts of Burma present some interesting points of difference.

Although, at first sight, the matrix of the Burma rubies (a crystalline

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[1] *Zeits. Kryst.* Vol. XXIV. (1895), p. 285.

[2] "Corundum-bearing Rock from Yogo Gulch, Montana," by L. V. Pirsson. *Amer. Journ. Sci.* 4th Ser. Vol. IV. (1897), p. 421.

"Crystallography of the Montana Sapphires," by J. H. Pratt. *Ibid.* p. 424.

[3] *Neues Jahrb. Min.* &c., 1896, Bd. II. Taf. VII.

limestone) may seem so different from that of the rubies of Cowee-Creek (an amphibolite with garnets, and sometimes with a basic felspar), yet a connection may still be shown to exist between the two cases. One of us has brought forward evidence to show[1] that the limestone of Burma has been formed by the slow alteration of a lime-felspar. Whether the corundum pre-existed in the highly-basic felspathic rock, however, or was formed at a later stage, there is no positive evidence to show. But the idea of its existence in the silicate rock originally is supported by the wonderfully corroded state of the corundum crystals.

The magma giving rise to pyroxene gneisses and granulites of Burma may not have differed greatly in composition from that giving rise to the amphibolites, eclogites, and basic gneiss of North Carolina; and, in either case, corundum may have been formed by the separation of dissolved alumina. The great promise which is held out by the fine colour and quality of many of the ruby crystals from this new locality would seem to warrant a continuance of the prospecting work lately inaugurated there, and it is to be hoped that the interesting problem of *the true origin of these rubies* may be definitely settled when the explorations on Cowee-Creek shall have furnished fuller data and more conclusive evidence concerning the primary condition of the associated minerals and the nature and relations of the rocks of the district.

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1 *Phil. Trans.* Vol. 187A (1896), pp. 151–228.

On the Crystallography of the Rubies from Macon County, North Carolina.

By Dr. J. H. Pratt.

THE ruby crystals from the Cowee Valley, Macon County, North Carolina, show a very wide variation in their development. Although many of the crystals are so striated that no crystallographic measurements were possible on the reflecting goniometer, the faces were readily identified by means of the contact goniometer. On some of the crystals the faces were bright and smooth, making them well adapted for measurement on the reflecting goniometer. The following references are to Plate I.

Among the crystals examined there were two common habits noticed, one, as shown in Figs. 1 and 2, which is a combination of the base $c(0001)$ and the unit rhombohedron $(10\bar{1}1)$; the other, represented by Figs. 3 to 6, where the prism $a(11\bar{2}0)$ is very prominently developed. The rhombohedral crystals vary from those where the base is largely developed, having a diameter of 12 mm., while the rhombohedron is only 1·5 mm., to some (Fig. 1) which have the base and rhombohedron more equally developed. The majority of these crystals have, however, the base more largely developed, thus giving the crystals a flat tabular appearance. This rhombohedral development is very similar to that of the sapphires from Yogo Gulch, Montana, described by the author.[1]

On some of the prismatic crystals the prism reaches a length of nearly 15 mm. in the direction of the c axis, and has the rhombohedron but slightly developed (Fig. 3), while on others the prism is very short and the rhombohedron sometimes is wanting, as represented in Figs. 4 and 5.

Another habit of these crystals is shown in Figs. 7 and 8. There the pyramid $n(22\bar{4}3)$ is well developed. This face was identified by means of the contact goniometer, the measurements approximating closely to the calculated angles. The usual form of these crystals is shown in Fig. 7, where the faces $c(0001)$, $a(11\bar{2}0)$, $r(10\bar{1}1)$ and $n(22\bar{4}3)$ are nearly equally developed. On some of the crystals the prism is very prominent, being 8 mm. in length in the direction of the c axis, while the pyramid is only 1·5 mm. On others the pyramid is only very slightly developed. A few crystals were examined which showed only the presence of the base, the rhombohedron and the pyramid, as represented in Fig. 8. The crystals,

[1] *Amer. Journ. Sci.* Vol. IV. 1897, p. 424.

measuring up to 7 mm. in diameter, were doubly terminated and nearly perfect in their development.

The crystals represented by Figure 7 are similar to those described by Max Bauer[1] from the Burma district, and are almost identical in form with a sapphire crystal figured by the author, from Emerald Bar, Canon Ferry, Magher County, Montana.

Although both the basal and rhombohedral planes are very often striated, it is only on the basal planes that these are sharp and distinct and can be measured. The striations are parallel to the three intersections of the base c with the rhombohedron r, as shown in Fig. 5.

A very common development that was noticed in nearly all the flat rhombohedral crystals, and on many of the prismatic crystals, is a repeated growth on the basal plane of the rhombohedron $r(10\bar{1}1)$ and the base $c(0001)$, as represented in Figs. 1 and 6.

To better illustrate the variation in these growths, a series of figures (9 to 14) have been drawn in basal projection. In Figs. 9 and 10, which represent the more common development of these repeated growths, there is but one secondary rhombohedron and base, which sometimes has one of its rhombohedron faces a continuation of one of the rhombohedron faces of the crystal. Figs. 11 and 12 represent repeated growths, the faces of which are separate and distinct from each other and from the faces of the main crystal. In the crystals represented by Fig. 12, when the secondary growths are but slightly developed the basal plane of the crystal has the appearance of being striated with triangular markings. In Figs. 13 and 14 there are represented a series of growths where a number of the rhombohedral faces coincide.

Some of the pyramidal crystals (Figs. 7 and 8) also showed the development of the secondary growth of rhombohedron and base.

The thickness of the rhombohedron of the secondary growth varies from those that are so thin that they appear like striations to some that are 2 mm. thick.

This same style of development has been described by Bauer[2] as occurring in the Burma rubies, and it has also been described by the author[3] as occurring on the Montana sapphires.

A few crystals were observed on which there was a secondary growth parallel to the prism $(1\bar{1}20)$.

[1] *Neues Jahrb. Min.* 1896, II. 197.

[2] *Loc. cit.* p. 209.

[3] *Amer. J. Sci.* Vol IV. 1897, p. 424.

Communications from the Oxford Mineralogical Laboratory.

On the constitution of the natural Arsenates and Phosphates.

By E. G. J. Hartley, B.A.

[Read Jan. 31st, 1899.]

Part II.—*Pharmacosiderite.*

THIS mineral, which until now has been regarded as a hydrated arsenate of iron, was mentioned as far back as 1790 by Proust and also by other mineralogists about the same time. In 1801 Chenevix (*Phil. Trans.* 1801, 220) gave an analysis of an arsenate of iron, but it differs very much in composition from pharmacosiderite in that it contained 9 per cent. of copper. Probably it was not a pure specimen of this mineral. Vauquelin also published an analysis of an iron arsenate which was probably pharmacosiderite (Brongniart, *Traité de Min.*, 1807, II. 182), since he describes it as crystallising in cubes. He gave the following numbers:—

Fe_2O_3	...	= 48	per cent.
As_2O_5	...	= 18 to 20	,,
H_2O	...	= 32	,,
$CaCO_3$	...	= 2	,,

Neither of the above analyses referred to is satisfactory, as at that early date exact analytical methods of separating iron and arsenic acid were not known.

Berzelius (*Akad. Handl. Stockholm*, 1824, 354) published an analysis of pharmacosiderite, giving the following numbers:—

As_2O_5	...	= 37·82	per cent.
P_2O_5	...	= 2·53	,,
Fe_2O_3	...	= 39·20	,,
CuO	...	= ·65	,,
H_2O	...	= 18·61	,,
Residue	...	= 1·76	,,
		100·57	,,

This corresponds approximately to the formula $4Fe_2O_3.3As_2O_5.15H_2O$, for which the following are the percentages:—

As_2O_5	...	= 43·1
Fe_2O_3	...	= 40·0
H_2O	...	= 16·9

Since this analysis was not altogether satisfactory, and a simple formula cannot be readily deduced from the numbers, it seemed desirable to make a further analysis of the mineral.

The specimens taken for this purpose were from the mineral collection in the Oxford University Museum. They were certainly old Cornish specimens.

Green crystals were chosen as far as possible, as they seemed to be the purest and least altered, and the portion taken for analysis was carefully picked out under the microscope. An examination of some very fresh-looking brown crystals on one specimen showed that the brown colour was only due to surface alteration, since on crushing them they could be seen under the microscope to be nearly all green, with thin flakes of the brown material.

The specific gravity of the material analysed was found to be 2·798; the determination was made by means of a diffusion column of benzene and methylene iodide, by comparing the depths at which the mineral and beads of known specific gravity remained suspended.

The crystals analysed all showed the usual weak birefringence of pharmacosiderite, and a banded structure parallel to the cube faces was clearly visible between crossed nicols.

The following curious property of this mineral was observed.

On letting a good sized crystal stand for a few minutes in a solution of ammonia, the whole crystal became red, and afterwards, even when it was powdered as fine as possible, no green fragments could be seen remaining even in the middle of the crystal. The transparency of the crystal was not in the least degree affected by this treatment, neither were the optical characters altered. On allowing such a red crystal to stand in dilute hydrochloric acid for the same time, the green colour was restored to the whole crystal.

This experiment seems to show that the crystal is permeable to such liquids, though no pores are visible.

With regard to the water in pharmacosiderite, there is no doubt that some of it is only very loosely held. Experiments were made to ascertain the effect of different degrees of heat upon the crystals.

First the loss of weight of the mineral was determined, when finely powdered and subjected to a current of dry air; then the loss of weight

at 100° C.; and the loss of weight at about 130° C., at which temperature the crystals begin to turn brown.

Finally the total water was determined by igniting a weighed quantity of the mineral and weighing the water liberated.

The apparatus used was similar to that employed in the analysis of chalcophyllite (*Min. Mag.* 1899, XII. 121), a mixture of lead oxide and dioxide being used to retain the arsenic.

With regard to the rest of the analysis, the arsenic acid was estimated either by precipitation as sulphide and oxidation of the latter to arsenic acid by means of fuming nitric acid, and finally by precipitation as magnesium ammonium arsenate, or else by precipitation together with phosphoric acid directly, as the magnesium ammonium salt, in the presence of sufficient ammonium tartrate to prevent simultaneous precipitation of the iron. The iron and phosphoric acid were precipitated by ammonia when the arsenic had been removed as sulphide. They were then weighed together, and the phosphoric acid was afterwards separated from the iron by the molybdate method and thus estimated, its weight being then deducted from the combined weights of iron and phosphoric acid.

Since the colour of the crystals might suggest the presence of ferrous iron as a constituent of the mineral, some experiments were made in which a portion was dissolved in dilute sulphuric acid in an atmosphere of carbonic acid gas, and the solution tested with very dilute solution of potassium permanganate. Only two or three drops at most were decolourised by about half a gram of the mineral, so that only the merest traces of ferrous iron can be present.

Preliminary Analyses (I and II).

After making two analyses by these methods, a considerable deficit was noticed, and a more complete qualitative analysis revealed the presence of a small quantity of potash. This constituent was estimated in two separate portions as potassium platinic chloride. The first estimation was made on material from one of the specimens used in the previous analyses, but it is not certain to which it belongs, as it was picked from some fragments that had been kept from the previous analyses. The second determination of potash had to be made from another specimen altogether, of which there was not sufficient to make a complete analysis. The deficit was at first regarded as only due to experimental errors, and so most of the material at hand had been sacrificed for the other estimations; but the existence of potash was established in all the Cornish

specimens examined, and on p. 157 will be found a complete determination of all the constituents from a single specimen.

The analytical numbers are as follows :—

Estimation of Water.

·2749	gram lost in dry air	·0044	gram	H_2O, corresponding to	1·60 %
·2749	,, at 100° C.	·0268	,,	,,	9·75 ,,
·3198	,, in dry air	·0027	,,	,,	·84 ,,
·3198	,, at 100° C.	·0316	,,	,,	9·88 ,,
·3990	,, at 136° C.	·0571	,,	,,	14·31 ,,
·2216	,, at 180° C.	·0326	,,	,,	14·71 ,,
·3990	gave on ignition	·0784	,,	,,	19·65 ,,
·2069	,, on ignition	·0402	,,	,,	19·42 ,,

The above determinations were made on different specimens.

The next two analyses (I and II) were made on portions of two specimens respectively.

Estimation of remaining constituents.

I.

·2715	gram lost in dry air	·0022	gram H_2O	corresponding to	·81 % H_2O
·2715	,, at 150°	·0367	H_2O	,,	13·52 ,, H_2O
·2715	,, on ignition	·0533	H_2O	,,	19·63 ,, H_2O
·3136	gave	·1582	$Mg_2As_2O_7$	,,	37·53 ,, As_2O_5
·3136	,,	·0100	$Mg_2P_2O_7$	,,	2·04 ,, P_2O_5
·3136	,,	·1232	Fe_2O_3	,,	39·29 ,, Fe_2O_3

II.

·3603	gram gave	·1398	gram Fe_2O_3	corresponding to	38·81 % Fe_2O_3
·3603	,,	·0113	$Mg_2P_2O_7$	,,	2·06 ,, P_2O_5
·3027	,,	·1504	$Mg_2As_2O_7$	,,	36·85 ,, As_2O_5

Estimation of potash (a) on material used in the preceding analyses; (b) on new material.

(*a*)	·6082 gram gave	·1288 gram	$(KCl)_2.PtCl_4$	corresponding to	4·12 K_2O
(*b*)	·3136 ,,	·0434	$(KCl)_2.PtCl_4$	,,	2·68 K_2O

In Analysis II the proportion of water was not estimated, since it was abundantly clear from the preceding three determinations that the percentage of water is constant.

The following are the numbers obtained from the preceding analyses:—

	I.		II.		Mean result of water estimations.	
Total H_2O	19·63	...	[19·63]	...	Total water ...	19·63
As_2O_5	37·53	...	36·85	...	Water lost at about	
P_2O_5	2·04	...	2·06		130°	14·18
Fe_2O_3	39·29	...	38·81			
	98·49		97·35			
Deficit ...	1·51	...	2·65			
	100·00		100·00			

Since the deficit in these two analyses differs considerably, and since the percentages of potash determined directly in two different specimens are not at all in accordance, it is fair to assume that this constituent is very variable, and in fact two specimens from Königsberg, Hungary, were examined, and found to contain only a trace of potash.

If we consider the water contained in this mineral, it seems impossible to regard any of it as accidental, since while slight variations occur in the percentages under the varying conditions of the above experiments, the total amount seems to remain constant; and in the case where one sample lost more than another in a current of dry air, it lost less at 100° C., so that these results probably depend partly on the fineness of division of the powdered substance.

Nor does the exact percentage of water lost at 100° C. appear to have much significance, since the crystals hardly alter in appearance at this stage.

A real change, however, seems to begin to take place at 130°, as at this point the crystal liberates sufficient water to lose its transparency and green colour. It therefore seems that the percentage of water lost at about 130° should be taken into account in deducing a formula for this mineral.

Complete Analysis (III).

A subsequent and complete analysis of pharmacosiderite made on another Cornish specimen showed it to contain a slightly higher percentage of potash than any of the previously examined specimens.

The percentage of water was somewhat lower in this sample than in the others, which is remarkable, as it seemed to be constant in the three former determinations. The numbers obtained were as follows:—

III.

·3398 gram gave	·1702	$Mg_2As_2O_7$	=37·16	per cent.	As_2O_5
·3347 ,,	·0631	H_2O	=18·85	,,	H_2O
·3347 ,,	·1258	Fe_2O_3	=37·58	,,	Fe_2O_3
·3347 ,,	·0063	$Mg_2P_2O_7$	= 1·20	,,	P_2O_5
·3243 ,,	·0761	$(KCl)_2PtCl_4$	= 4·54	,,	K_2O
			99·33		

In proposing a formula for this mineral it is of course impossible to express in any molecular proportions the ratio between the potash and the iron, since the former is such a variable constituent. It is, however, possible to construct a formula which would express the constitution of the mineral if free from potash altogether, and to make a suggestion as to the part played by the potash.

The formula, which satisfies the ratios between the iron, arsenic acid and water, is $3Fe_2O_3.2As_2O_5.13H_2O$, or $2FeAsO_4.Fe(OH)_3.5H_2O$, in which the 5 molecules of water (15·53 per cent.) lost at about 130° are expressed as water of crystallisation. This gives the following percentages :

Total water	...	...	19·94	per cent.
Fe_2O_3	...	...	40·88	,,
As_2O_5	...	...	39·18	,,
			100·00	

The only way in which the potash can be brought into this formula is by supposing that some of the hydrogen in the hydroxyl groups is replaced by potassium. This would explain why, in the specimen, which contained most potash, all the other constituents showed a smaller percentage. If, on the other hand, the potash be considered to be present as potassium arsenate, forming a double salt with the iron arsenate, the percentage of arsenic acid ought to be higher in those specimens which contain most potash, but it is seen in fact that the ratio of iron, water and arsenic acids remains fairly constant in all cases.

An additional piece of evidence may be adduced in favour of the view that potash is an essential constituent of the Cornish pharmacosiderite, and not merely an impurity, though it may be present only in very small quantities.

While picking out material for the last analysis, it was found that the pharmacosiderite was closely associated with scorodite. Some of the latter was carefully picked out, but was found to be absolutely free from potash. Here then is a case of the two arsenates of iron side by side,

one containing potash in considerable quantity, and the other containing none. It may also be mentioned that one of the Königsberg specimens somewhat differed in crystalline form from the Cornish specimens, owing to the presence of tetrahedron faces; and this difference may possibly be related to the very small percentage of potash which it contained. The other Königsberg specimen, though it appeared to resemble the Cornish crystals in form, was considerably "weathered."

The final result of the above investigation is to propose the following formula as best representing the properties and constitution of pharmaco siderite:—

$$2FeAsO_4.Fe\,[O(H,K)]_3.5H_2O.$$

Note.—The presence of potassium was established by means of the microchemical test in all the specimens of pharmacosiderite examined. It is sufficient to immerse a fragment of the mineral in a drop of dilute hydrochloric acid and to add a drop of platinum chloride in order to obtain the characteristic octahedra of potassium platinic chloride.

On Langbeinite from the Punjab Salt Range.

By F. R. Mallet, F.G.S.,

Late Superintendent, Geological Survey of India.

[Read April 11th, 1899.]

In the eleventh volume of the *Mineralogical Magazine*, p. 317, in connection with the occurrence of blödite at the Mayo mines, in the Salt Range, allusion is incidentally made to a potassio-magnesian deposit, which was discovered there by Dr. H. Warth in 1873. It occurred as a lenticular stratum in the 'kallar' (impure rock salt) band separating the Sujewal and Purwálla salt beds. The material was more or less mixed up with the 'kallar' itself, and the deposit appeared to be of very limited extent.[1] I am informed by Dr. Warth that no further deposit of the kind has been discovered, so far as he knows; but this does not prove very much, for, since his retirement from the management of the mines, no search for potassium salts seems to have been made.

Specimens sent to the Geological Survey Laboratory, in Calcutta, were examined by Mr. A. Tween, whose analyses, given below, were published in the Catalogue to the Collection of Indian Geological Specimens sent to the Vienna Exhibition of 1873.[2]

	No. 1. Colourless salt.	No. 2. Pink-coloured salt.
KCl	3·80	61·43
NaCl	—	29·32
K_2SO_4	38·00	—
$MgSO_4$	58·02	7·78
H_2O	·62	2·10
	100·44	100·63

Specimens in the Vienna collection similar to No. 2 were examined by Professor Tschermak, who described them as "a white or reddish

[1] *Mem. Geol. Surv. India*, 1878, XIV. 80.

[2] Reprinted in Mr. A. B. Wynne's memoir on the geology of the Salt Range, *Mem. Geol. Surv. India*, 1878, XIV. 80.

granular mixture of sylvite, rock salt, and kieserite. The sylvite and rock salt can be at once recognised by the cleavage and flame reaction. The kieserite, which occurs in grains having a maximum diameter of 12 millimetres, is colourless, and shows the hardness and cleavage that I have given for the Hallstadt mineral.[1] In places, also, the kieserite is compact. An estimation of the water gave 12·99 per cent., which agrees with the theoretical amount, 13·04. From the kieserite changing, in a moist atmosphere, into epsomite, the pieces formed of that substance become quite disintegrated at the surface, and exhibit a constantly deciduous coating. In some pieces sylvite greatly predominates. Whether some kieserite also occurs in these, as might be conjectured in such association, has not yet been determined, for I have only been able to submit small pieces to examination."[2]

The colourless salt does not seem to have come under Professor Tschermak's observation. In Part IV. of *A Manual of the Geology of India*, published in 1887 (p. 142), I included it amongst the minerals of India, as a doubtful sulphate of magnesium and potassium, and remarked that, neglecting the KCl (doubtless intermixed sylvite) and H_2O, the percentages of $MgSO_4$ and K_2SO_4, amounting respectively to 60·43 and 39·57, when calculated to 100, although not corresponding accurately to any simple ratio between the bases, are fairly near 58·00 and 42·00, those required for the formula $(\frac{2}{3}Mg+\frac{1}{3}K_2)SO_4$, which is equivalent to $2MgSO_4.K_2SO_4$. I did not, however, consider that it would be justifiable to assume that the substance was a true double salt (and hence a simple mineral) without further examination, which circumstances did not allow of my making at that time.

Since then the existence of the compound just mentioned has been placed beyond doubt. In 1884 potassium salts were struck by a boring at the future mine of Wilhelmshall, north of Halberstadt, in Prussian Saxony. The result of Dr. S. Zuckschwerdt's examination of the fragments brought up led him, in 1891, to announce the discovery of "Langbeinite, a new potassium-magnesium sulphate," which his analyses, after he had freed the mineral from accompanying rock-salt, showed to agree very closely in composition with that required by the formula $K_2SO_4.2MgSO_4$.[3] Observations made by Director Steckert, after the

[1] *Sitzungsber. Wien. Akad.* LXIII. 1871, 305.

[2] *Tscherm. Min. Mitth.* 1873, 135; *Jahrb. d. k. k. geol. Reichsanst. Wien*, 1873, XXIII.; *Rec. Geol. Surv. India*, VII. 1874, 64.

[3] *Zeits. f. angewandte Chemie*, 1891, 356.

Wilhelmshall deposit had been opened out by mining, showed that the langbeinite always occurs in the older rock-salt beds, and is a mineral of primary formation, taking the place of polyhalite in those parts of the potassium-salt deposits where the quantity of calcium sulphate is insufficient for the formation of the latter mineral.[1] Comparatively recently langbeinite has been discovered in large quantity near Wolfenbüttel in Brunswick, where it occurs in the same way as at Wilhelmshall; and it has been found likewise in Westerregeln, and in Neu-Stassfurt, but under different circumstances, being in association with sylvite as well as rock salt, and partly of secondary formation.[2] Near Bernburg, again, the mineral occurs abundantly, overlying the carnallite stratum and beneath beds of rock-salt.[3] The first crystals of the mineral discovered were obtained at the last-mentioned locality, by Dr. Siebert, in 1897, and submitted to an elaborate optical and crystallographic examination by Otto Luedecke, who showed that the very complex crystals belong to the tetartohedral group of the isometric system.[4]

In the light of the above researches on the langbeinite of Germany, there seemed little room for doubting that the Punjab salt was of the same nature; but, in order that the question might be placed beyond the region of supposition, all the available material in the Museum was, at my request, lately sent to me for examination by the Director of the Indian Geological Survey, Mr. C. L. Griesbach, C.I.E.

Of the two specimens received, one (*Mineral Register, No. G 861*) is labelled as from the Mayo Mines, and presented by Dr. Warth, with the date of analysis added in Mr. Tween's handwriting, and is noted in the laboratory book as "colourless salt from the Salt Range." It is beyond question that to which Mr. Tween's analysis No. 1 refers. The other specimen will be referred to later on.

The colourless salt (*G 861*), of which there is about 4 ozs., is in irregular pieces, the largest about $3\frac{1}{2}$ centimetres long; and, but for a few scattered inclusions of reddish salt (NaCl, coloured by Fe_2O_3), mostly not larger than a pin's head, though two or three are some millimetres in diameter, there is no macroscopic foreign matter. Only one piece (on which two adjacent faces are visible) shows any outward sign of crystallisation, and no cleavage is apparent. The fracture is uneven, or some-

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[1] H. Precht, *Zeits. f. angewandte Chemie*, 1897, 68.

[2] H. Precht, *ibid.* 1897, 68.

[3] *Ibid.* 1897, 68; and O. Luedecke, *Zeits. Kryst. Min.* XXIX. (1898), 255.

[4] *Loc. cit.*

times conchoidal, and the hardness about 4. A determination of the specific gravity, by means of turpentine, in which the mineral is insoluble, gave 2·84 at 60° F., the pieces used being free from the NaCl mentioned above, and having surfaces composed of newly-made fractures. Portions of the mineral are whitish and translucent, owing to inclusions, but where it is free from such, or nearly so, it is colourless and transparent. In polarised light the mineral itself is isotropic. Luedecke, by the examination of slices (from near Bernburg) in sodium light between crossed nicols, was unable to detect any circular polarisation; but, as the material he employed was not fully transparent, he remarked that it was desirable that the experiment should be repeated on more perfect sections. I may add, therefore, that I obtained a similar negative result with the Punjab mineral, the plates used being perfectly transparent, and one of them about 4 millimetres thick.

The inclusions alluded to above, which, although nearly absent in some parts of the mineral, are abundant in others, range in size to over half a millimetre in length, though the great majority are much smaller. They are mostly of very irregular outline, but a few of them are lath-shaped, sometimes terminated by one or two pairs of parallel lines. In ordinary light the inclusions are as transparent and colourless as their host, and while the dark border to them is narrow, even where most pronounced, in some it is scarcely apparent. Hence they are not strongly differentiated from the enclosing mineral, and some are scarcely visible with the light mentioned, although very marked between crossed nicols. A good many of them contain bubble-like inclusions, with a dark border so broad that there is a comparatively small spot of light in the centre. These are presumably gas cavities. In no instance was any movement detected, or any indication of the presence of liquid.[1] Similar gas cavities, sometimes of larger size and more irregular outline, also occur in the langbeinite itself.

The transparent (solid) inclusions may be divided into a minority, which are isotropic, and the remainder, which are birefringent. Of the latter, those with irregular outlines either extinguish uniformly over the whole area, or else the area is divided into a few subordinate ones, often not more than two or three, in each of which uniform extinction takes place. There are but few lath-shaped inclusions, the extinction in most of them being oblique, and in the remainder straight, suggesting monoclinic crystallisation.

[1] For reasons given below, water could scarcely exist, as such, in the inclusions.

The fragments of mineral selected for quantitative analysis were free from macroscopic impurity, and the surfaces were all freshly made fractures. Water dissolved the sample rather slowly, but completely, without a trace of residue. The result obtained was :—

		Calculated to 100.	Theory.[1]
K_2O	22·23	22·55	22·70
MgO	19·08	19·36	19·41
SO_3	57·27	58·09	57·89
NaCl	·41	—	—
H_2O	·84	—	—
	99·83	100·00	100·00

The sodium is evidently combined with the chlorine,[2] and the isotropic inclusions mentioned above should doubtless be referred to the resulting salt. The analysis just given shows that the birefringent inclusions must consist of potassium sulphate or magnesium sulphate, or both, in some form or other, and the close approximation of the analysis to the theoretical composition of langbeinite, suggests that the two sulphates are present in the inclusions in something like the same ratio as in the langbeinite itself. This condition would be satisfied if the inclusions consisted of kieserite or epsomite, and picromerite, in the proportion of one molecule of each, and such a mixture would be in accordance with the presence of water as shown by the analysis, and with the birefringence of the inclusions.

The langbeinite, when exposed, in powder, to the air, absorbs water rather quickly, an increase in weight of nearly 5 per cent. in 24 hours having been noticed. On the exposure being continued until the mineral ceases to gain in weight, the total increase is found to be rather less than 57 per cent., the precise amount depending on the temperature and humidity of the air at the time. Thus ten weighings of the same sample at different times gave results varying between 56·36 and 57·01 per cent.[3] As an absorption of 13 molecules of water equals 56·44 per

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[1] K_2SO_4, 42·00 per cent.; $MgSO_4$, 58·00 per cent.

[2] The quantities found were Na ·15, Cl ·26, while theoretically the proportion is ·17 to ·26.

[3] Allowing for the water already present in the langbeinite (and the NaCl), this is equal to an absorption of about 58 to 58½ per cent., the excess over the theoretical amount being no doubt due to hygroscopic moisture. The latter cannot be extracted by H_2SO_4, as efflorescence takes place under such circumstances.

cent., it is clear that the decomposition of the langbeinite takes place in accordance with the following equation:—

Langbeinite. Water. Picromerite. Epsomite.
$$K_2SO_4.2MgSO_4 + 13H_2O = K_2SO_4.MgSO_4.6H_2O + MgSO_4.7H_2O.$$

The second specimen received from Calcutta (*Mineral Register, No. G 860*) is likewise from the Mayo Mines, and aggregates about half a pound, in pieces up to 5 or 6 centimetres long. The substance is grayish-white in some parts, pale reddish in others, and shows a rather coarse granular structure. I have, as yet, examined it qualitatively only, but it appears beyond doubt to be the material to which Mr. Tween's second analysis and Professor Tschermak's observations refer. It may, however, contain a larger proportion of kieserite than the portion examined by Mr. Tween, and I likewise picked some langbeinite out of it, the largest piece being about 2 centimetres long.

It is clear, therefore, that the saline deposit in question was composed of at least four minerals, their relative proportions varying considerably, perhaps greatly, in different parts of the stratum.[1]

The langbeinite melts at a red heat, and, on cooling, solidifies to a white, more or less distinctly crystallised, mass. This observation naturally suggested an easy method for its artificial production, and the inference was confirmed by experiment. When powdered K_2SO_4 and $MgSO_4.7H_2O$ are mixed (more conveniently after dehydration of the latter) in the molecular proportion of 1 to 2, and ignited, the mixture fuses at a full red heat to a clear transparent liquid. During cooling and solidification there is a considerable amount of crepitation. The resulting white mass generally has one or more drusy cavities in the interior, the crystals on the walls of which are (geometrically) octahedra, with faces some of which are smooth and others somewhat cavernous. A few crystals show faces of the rhombic dodecahedron, replacing octahedral edges. The crystals tend to arrange themselves with similar orientation, and sometimes form columns composed of octahedra with their respective axes parallel. The artificial mineral is isotropic, like the natural one. During fusion SO_3 is slowly given off, and eventually the melt becomes pasty from admixed magnesia, while it no longer dissolves completely in water.

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[1] Since the above was written Dr. Warth has informed me that the salts in question were found at two spots, about 300 feet apart. At one of these magnesium salts predominate; at the other, potassium salts; the latter may perhaps have been a little higher up (on a higher horizon) in the Kallar bed than the other, but this is uncertain.

In 1880 Dr. H. Precht described the artificial production of a salt to which he assigned the formula $K_2SO_4.2MgSO_4.H_2O$, but which, after the publication of Dr. Zuckschwerdt's results in 1891, he regarded as $K_2SO_4.2MgSO_4$. It is precipitated at a boiling heat, preferably at a steam pressure of 2 or even 4 atmospheres, from a concentrated solution of magnesium chloride, with potassium sulphate and excess of magnesium sulphate.[1] This latter method will, perhaps, be regarded as not without interest in connection with the views expressed by Messrs. Middlemiss and Holland as to the origin of the salt marl and gypsum of the Salt Range.[2]

In conclusion, I may add that the known minerals associated with the rock salt of the Salt Range include the following[3] : –

1st. Of Primary Formation.

Rock-salt (stratified; in beds of immense thickness and extent). A. B. Wynne, *Mem. Geol. Surv. India*, 1878, XIV. 76, 213, 231, 284.

Sylvite[4] (stratified; the mineral has been found in one or two spots only, mixed with rock-salt, kieserite, and langbeinite). G. Tschermak, *Min. Mitth.* 1873, 135, and *Rec. Geol. Surv. India*, 1874, VII. 64.

Anhydrite (stratified; more or less mixed with gypsum; *cf.* secondary gypsum). A. B. Wynne, *loc. cit.* 74; T. H. Holland, *Rec. Geol. Surv. India*, XXIV. 1891, 235.

Gypsum? (stratified; in extensive beds, as a rule overlying the rock-salt; *cf.* secondary gypsum). A. B. Wynne, *loc. cit.* 75, 300.

Kieserite (stratified; *cf.* sylvite). G. Tschermak, *loc. cit.*; F. R. Mallet, *Min. Mag.* XI. 1897, 317.

Langbeinite (stratified; *cf.* sylvite). F. R. Mallet, *Min. Mag.* Vol. XII, 1899, 159.

Dolomite (stratified). A. B. Wynne, *loc. cit.* 74, 134, 231, 267; C. S. Middlemiss, *Rec. Geol. Surv. India*, XXIV, 1891, 26; H. Warth, *ibid.* XXIV. 69.

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[1] *Chemische Industrie*, III. (1880), 418, and *Zeits. f. angewandte Chemie*, 1897, 68.

[2] *Records, Geol. Surv. India*, XXIV. 26 and 235.

[3] The references are far from complete, only some of the more important being given. For the literature of the subject, *Mem. Geol. Surv. India*, Vol. XIV.; *A Manual of the Geology of India*, Parts II. III. and IV., and *Rec. Geol. Surv. India*, XXIV, 19 and 230, may be consulted.

[4] The primary nature of the sylvite and kieserite, and secondary character of the selenite, glauberite, and blödite, was pointed out by Dr. Warth in a letter respecting blödite that I received from him in 1897.

Quartz (as crystals in the anhydrite and gypsum). H. Warth, *Inland Customs Administration Report*, 1870-71; A. B. Wynne, *loc. cit.* 268; T. H. Holland, *Rec. Geol. Surv. India*, XXIV, 1891, 231.

2nd. Of Secondary Formation.

Halite (crystals in fissures of the rock salt, and fibrous). H. Warth, *Inland Customs Admin. Report*, 1869-70, Appendix H; *Manual Geol. Ind.*, IV. 34.

Gypsum (altered anhydrite). A. B. Wynne, *loc. cit.* 74; T. H. Holland (who holds that much of, possibly all, the gypsum of the Salt Range is altered anhydrite), *Rec. Geol. Surv. India*, XXIV. 1891, 235 (altered dolomite?); C. S. Middlemiss, *ibid.* 26.

Selenite (crystals in fissures of the rock salt). H. Warth, *Mem. Geol. Surv. India*, XIV. 1878, 80; *Min. Mag.* XI. 1897, 311.

Glauberite (crystals in fissures of the rock salt). H. Warth, *cf.* selenite; W. Schimper, *Zeits. f. Kryst.* I. 1877, 70.

Blödite (crystals in fissures of the rock salt). H. Warth, *Min. Mag.* XI. 1897, 311; W. Schimper, *loc. cit.*; F. R. Mallet, *Min. Mag.* XI. 1897, 311.

Picromerite? (probably exists in small quantity, owing to the hydration of langbeinite). *Cf.* p. 163.

Epsomite (as an efflorescence, due, in part at least, to hydration of kieserite). H. Warth, *Inland Customs Admin. Report*, 1869-70, Appendix H; G. Tschermak, *loc. cit.*; A. B. Wynne, *loc. cit.* 79 (probably also in small quantity, owing to hydration of langbeinite). *Cf.* p. 163.

On a mass of Meteoric Iron from the neighbourhood of Caperr, Rio Senguerr, Patagonia.

By L. Fletcher, M.A., F.R.S.,
Keeper of Minerals in the British Museum.

[Read April 11th, 1899.]

IN the month of September, 1869, Captain Musters, who was at that time making an expedition through Patagonia, had his attention called to a heavy mass of material which he took to be marble. In the account of his journey he afterwards wrote (from memory) as follows[1]:—

"There is in this place, which is called by the Indians Amakaken, a large spherical boulder of marble, which it is the custom of the Indians to try their strength by lifting. Casimiro informed me that this stone had been there for many years, and the custom was very old. It was so large and heavy that I was just able to grasp it with both arms and raise it to the level of my knees, but some of the Indians managed to lift it to their shoulders."

Amakaken is indicated on Musters' map as situated in longitude 71°56′ West of Greenwich, and latitude 48°10′ South. The above-mentioned Casimiro, who accompanied Captain Musters throughout the expedition, had been recognised by the Argentine Government in 1865 as head chief of the Tehuelches,[2] the natives inhabiting the interior of Patagonia. The Tehuelches are by country, race, language and character altogether distinct from the Pampas Indians.[3]

Many years later, on the 4th of April, 1896, the mass was seen by the Director of the State Museum of La Plata, Dr. Francisco P. Moreno, then making a voyage of exploration in the interior of Patagonia. Dr. Moreno perceived that the material was not marble but iron, and recognising that it must be of meteoric origin, secured the mass (weighing 114

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[1] *At Home with the Patagonians.* By George Chaworth Musters. London, 1871, p. 87.

[2] *Ibid.* p. 46.

[3] *Ibid.* pp. xix, xx.

kilograms, or 251 lbs.) for the La Plata Museum. In January last Dr. Moreno came to London to be at hand to give geographical information on behalf of the Argentine Government to the Commission appointed to settle by arbitration the boundary of Argentina and Chili; and he took the opportunity of bringing with him, in addition to other specimens of scientific interest, a model of the meteorite and a small fragment weighing 78 grams (2¾ oz.) which had been broken by him from a corner of the original mass. These he presented to the British Museum for examination and preservation.

Dr. Moreno reports that the name Amakaken (*i.e.* Emelk'aiken) was given by Captain Musters through a slip of memory, and that the place was really farther north on the plateau south of Rio Senguerr, Chubut Territory, situated about longitude 70°20′ West and latitude 45°15′ South; the nearest place with a name being a tribal encampment called in the Gennaken language Caperr.

According to measurements taken from the model, the mass is 48 cm. (19 in.) long, 31 cm. (12¼ in.) broad, and 27 cm. (10½ in.) high. The shape is irregular, but one side, parallel to the length, is sufficiently flat to afford a convenient base. The surface, like that of most meteoric irons, presents both large and small concavities. One of the former is 10 cm. across; one of the latter, nearly a hemisphere, is 3 cm. across.

That the structure of the material belongs to the kind termed octahedral is very manifest from mere inspection of the surface of fracture of the fragment, for the simple action of air and moisture has already sufficed to differentiate the constituent alloys and reveal their arrangement.

Relative to a solution of copper sulphate, the iron is "active," the reduced copper being visible within one or two minutes from the beginning of contact.

The iron is soft, and is thus easily cut with a hack-saw. No troilite or silicates were to be seen on any of the small faces which were prepared and polished.

A polished face (40 mm. long and 17 mm. wide), the largest which could be got from the fragment, was etched with bromine-water and gave distinct Widmanstätten figures. In this section the beams of dull grey kamacite have an average width of 1 mm. Occasionally there are three or four of them in immediate succession without any evident intervening plessite, their edges being only roughly rectilinear and parallel. As usual, each beam of kamacite is bordered by a thin bright line of tænite, which soon after the etching acquires a yellow tint. The plessite is comparatively plentiful, and occupies a considerable part of the etched

surface, one area being 5 mm. long and 5 mm. wide, and a second 3 mm. long and 2½ mm. wide. The ridges or "combs," described by Reichenbach, are very conspicuous, and appear to result from thin and numerous plates of tænite traversing the plessite.

Embedded directly in the kamacite, and not separated therefrom by lines of tænite, are some thicker lustrous steel-gray homogeneous-looking enclosures which were found to be schreibersite. As the latter mineral (phosphide of iron and nickel) is very similar in aspect to cohenite (carbide of iron and nickel) and may easily be mistaken for it, a small piece of iron containing one of these enclosures was cut out and filed down until the greater part of the enclosing iron had been removed. Owing to the probable brittleness of the small enclosure, the mechanical reduction was not carried further, but the fragment was now immersed in cold dilute hydrochloric acid (1 in 20). The enclosure immediately became silver-white, and remained so while in the acid, but the enclosing iron at once became dull black, and continued so during the solution. After two days the enclosure dropped out of the fragment, and could be separately examined. It proved to be a phosphide, and therefore schreibersite. It was unaffected by a solution of copper ammonium chloride.

The etched surface is also speckled with other very minute enclosures which have the same lustre and colour as the larger ones (schreibersite). The small specks and the short thin lines of this material appear here and there to take the place of tænite, while in other parts they lie between tænite and adjacent kamacite.

Small fragments of the iron were allowed to stand for some weeks in cold dilute hydrochloric acid (1 in 20), which was occasionally renewed. The greater part (kamacite) became dull black, and slowly passed into solution. The residue consisted of (1) lustrous thin plates, containing no phosphorus, and quickly attacked by copper ammonium chloride solution (tænite); (2) some dull black material dissolving immediately in *aqua regia* and containing no chromium, copper, sulphur or phosphorus: it is presumably an iron-nickel alloy, possibly another form of the tænite; and (3) schreibersite. There was no graphitic carbon, silica or silicate. The tænite and schreibersite were not sufficient in quantity to allow of their quantitative analysis.

Relative to water at 4° C., and allowing for displaced air, the specific gravity at 18¼° C. of two thin slices, together weighing 4·3424 grams, was determined to be 7·837 (uncorrected 7·86).

These two thin slices were dissolved in *aqua regia*, and left an unweighable residue consisting of a few black particles of almost microscopic

size in which no chromium could be detected by the blowpipe. After removal of the nitric acid by evaporation to dryness with hydrochloric acid (when no silica was obtained), the material was brought again into solution and divided into five equal portions, which were analysed according to the methods mentioned in a previous paper,[1] except that the iron was precipitated four times instead of twice by sodium acetate before its final precipitation by ammonia. The phosphorus was determined twice, once from a special portion of the solution by the method previously mentioned, and a second time by separation from the ignited iron precipitate by the ammonium sulphide and molybdic methods: the numerical results were virtually identical. The nickel and cobalt were precipitated twice as higher oxides by sodium hydrate and bromine-water, and weighed together in the metallic state. The cobalt was then separated by the nitrite method, and weighed as potassium cobalt sulphate.

The following numbers were obtained for the percentage composition:—

	Caperr, Patagonia.	The Joel iron, Atacama.
Iron	89·87	90·45
Nickel	9·33	8·80
Cobalt	0·53	0·54
Phosphorus ...	0·24	0·26
Chromium ...	trace	—
Copper	trace	trace
Sulphur	nil	nil
	99·97	100·05

For the purpose of comparison, the percentage chemical composition of one of the Atacama meteoric irons,[2] to which there is a considerable resemblance of structure, is given in the last column.

This is the first meteorite found in Patagonia, and its latitude is the most southern yet recorded for any meteoric iron. The next in point of southern latitude was the large Australian mass (now in the British Museum), which was found in latitude 38°11′ S., at Cranbourne, near Melbourne.

[1] *Mineralogical Magazine*, 1887, Vol. VII, p. 124.

[2] *Ibid.* 1889, Vol. VIII, p. 263.

On the Cliftonite and Tænite of the Meteoric Iron found in 1884 in the Sub-district of Youndegin, Western Australia.

By L. Fletcher, M.A., F.R.S.,
Keeper of Minerals in the British Museum.

[Read June 20th, 1899.]

In a previous paper, published in 1887,[1] the author described some remarkable crystals of graphitic carbon (Cliftonite) obtained from the meteoric iron of Youndegin, Western Australia; the isolated material weighed only 3 milligrams, and had been left as an insoluble residue after the treatment of 8·32 grams of the iron with *aqua regia*.

1. *Limited distribution of the Cliftonite in the mass.*

In the following year (1888), with a view to isolating more of the graphitic crystals and at the same time other mineral constituents of the mass, a large piece of the same meteoric iron, filed free from rust and weighing 97·25 grams, was submitted to the action of slightly heated dilute hydrochloric acid (1 of S.G. 1·12 with 10 of water), the acid being renewed from time to time as exhaustion took place. The action was allowed to proceed night and day until, after the lapse of a fortnight, evolution of hydrogen was no longer manifest. During this time the undissolved residue was kept as free from disturbance as possible, for the graphitic crystals were known to be brittle and easily reducible to powder. During the action of the acid the first appearance of Cliftonite was carefully watched for, in order that the mode of occurrence of the crystals in the mass might be ascertained; but not a single crystal was seen in the course of the whole operation, and the undissolved residue itself, when afterwards examined, was found to be almost wholly attracted by the magnet, and the unattracted part to be completely dissolved by *aqua regia*. As already recorded,[2] two other fragments, weighing 7 grams and 2 grams respectively, had yielded no graphitic material on solution.

[1] *Mineralogical Magazine*, 1887, Vol. VII, p. 121.

[2] *Ibid.* p. 125.

The Cliftonite is therefore localised in one or more parts of the mass, and not uniformly distributed through it. The more common variety of graphitic carbon is also similarly local in its occurrence in meteoric iron, being present in various masses as large nodules.

2. *Tænite.*

During the solution small thin lustrous black plates, only slightly if at all attacked by the dilute acid, were seen to be distributed throughout the more soluble material, many of the plates being parallel to each other. Their appearance was so like that of graphite that it was at first expected they would prove to belong to that species; but on examination of the plates initially set free, they were found to consist of a material strongly attracted by the magnet, flexible, completely soluble in strong hydrochloric acid and also in nitric acid of S.G. 1·2; they had an immediate reductive action on a cold solution of mercuric chloride, and in a day or two passed completely into solution. They contained no phosphorus. After standing for two days in water, a plate became oxidised on the surface and lost its brightness.

From these characters it was inferred that, notwithstanding their black colour, the plates consisted of an alloy of nickel and iron belonging to the tænite group.

The thin plates, as set free, were pushed with a thick platinum wire into a separate dish, and were kept isolated from the rest of the undissolved material as being a comparatively definite and homogeneous constituent of the meteorite. When all the plates obtainable had been collected, they were again treated with dilute hydrochloric acid for some days. Further, a small quantity of adherent schreibersite was carefully broken off and removed; it was found through the sense of touch by means of the greater resistance felt when the particles of schreibersite on the flexible plates were pressed with the thick platinum wire: owing to their flexibility the plates themselves are somewhat yielding, and thus give a suggestion of softness when they are pressed with the wire. The plates were washed with water, afterwards with alcohol, and then dried and weighed (0·0870 gram). Later there were added some further plates which had been similarly obtained from small waste fragments of the iron produced during the cutting of the mass; their weight was not determined, but it must have been comparatively small.

In the course of the present year (1899) it was resolved to make a quantitative analysis of the alloy, notwithstanding the smallness of the amount available for the purpose. During the eleven years which had

passed since its isolation, the alloy had been lying in a weighing tube inside a closed box. It still retained its lustre, and appeared to have undergone no alteration.

(*a*). The weight, however, was now 0·1026 gram, and the excess (0·0156 gram) over the amount (0·0870 gram) isolated from the large piece was greater than was likely to be due to the plates which were obtained from the small waste bits of the iron, and had been added after the weight of the main material (0·0870 gram) had been determined.

(*b*). The material, though entirely attracted by the compass-needle, did not appear to be as strongly attracted as nickel-iron.

(*c*). Cold solution of mercuric chloride had no perceptible action on the plates even in the course of some days. In this respect the plates behaved quite differently from before; for in 1888, as already stated, the reductive action had been immediate. After a fortnight, although a flake was still apparently unacted upon by the mercuric solution, there was really only a thin crust of undissolved material left; for when touched with a wire the flake completely collapsed. On the other hand, a boiling solution had an immediate solvent action, only a trivial amount of black material being left. This black material was immediately dissolved by strong hydrochloric acid, and was therefore not carbon.

As a cold solution of mercuric chloride has no solvent action on the magnetic oxide of iron, the later behaviour of the plates is such as would result if they had been superficially changed into the black magnetic oxide.

(*d*). The specific gravity of the material, as determined from 0·0669 gram with the use of a 3-cub. cent. pyknometer, was 6·75. This number is so much below those corresponding to iron and nickel that, with every allowance for the difficulty of accurately determining the loss of weight in water for so small an amount of dense metal, it suggests an oxidation of the material. It may be mentioned that during the determination great difficulty was experienced in removing all the interpenetrant air; the plates were composite, and the air was only slowly removed from the intervening spaces by an oft-repeated use of the air-pump.

(*e*). The above-mentioned material, weighing 0·0669 gram, was treated with *aqua regia*, and in a short time was almost wholly dissolved. Long digestion, however, did not produce complete solution; a minute amount of insoluble reddish-purple pulverulent matter was still visible. It was collected and weighed by the double-filter method after being dried at 165° C. The colour had now changed from reddish-purple to black. The material weighed only 0·0006 gram. As it completely disappeared

on ignition, it was probably an organic compound, and was possibly due to the action of the *aqua regia* on a trace of Cohenite, a carbide of iron and nickel occasionally present in meteorites.

The solution was analysed according to the methods already described,[1] except that the number of precipitations with sodium acetate was six instead of four.

The resulting numbers were—

Iron	0·0385	gram.
Nickel (Cobalt) ...	0·0236	,,
Phosphorus ...	0·0004	,,
Total	0·0625	,,

Copper was found to be present, but its weight was not determined; though the amount was small, the proportion of the copper was probably larger than for an average piece of the meteoric iron itself. Only a trace of magnesium was found.

There was thus 0·0044 gram still unaccounted for. The deficit was presumably due to combined oxygen, for the analysis had been made with great care, and had proceeded without evident mishap. The still remaining material, weighing 0·0285 gram, was then heated in a porcelain boat in a current of hydrogen, and was found to experience a loss of 0·0018 gram. In the same proportion, 0·0669 gram of the material should lose 0·0042 gram, and the result is thus confirmatory of the above explanation of the deficit.

After the heating in hydrogen, the material was no longer black, but bright tin-white in colour.

If the small amount of phosphorus be deducted, as being in combination with iron and nickel as schreibersite having the formula Fe_2NiP, the percentage composition of the Youndegin tænite is—

Iron	61·87
Nickel (Cobalt)	38·13
	100·00

The alloy is therefore almost identical in chemical composition with that isolated by Cohen and Weinschenk from the Glorieta meteorite, the percentage composition of which was determined to be:—

Iron	63·04
Nickel (Cobalt)	36·96
	100·00

[1] This volume, p. 170.

A Three-Circle Goniometer.

By G. F. Herbert Smith, B.A.,

Assistant in the Mineral Department of the British Museum.

[Read April 11th, 1899.]

THE object of goniometrical measurement is to determine in the simplest and quickest manner possible the geometrical constants of crystals and the indices of their faces. The ideal instrument should enable the observations to be conveniently and quickly made, and present them in such a form that the indices of the faces may be easily calculated. It is claimed for the form of goniometer described in this paper that it does approximate to such an instrument. Before entering into the description it will not be out of place to discuss briefly the two types at present in existence, and point out their advantages and disadvantages.

I. *The One-Circle Goniometer.*

This instrument, which owes its conception to Wollaston, first made possible the accurate measurement of the angles between the faces of a crystal. In the original form the graduated circle was vertical, but Babinet afterwards introduced a goniometer with a horizontal circle. Improvements in details—such as the employment of telescope and collimator, mechanical means for adjusting the crystal, convenient object-slits, &c.—followed in due course, until finally we have the perfected instrument of the present day.

The grave objection to this form of goniometer is the necessity for readjusting the crystal for each zone, and consequently for identifying at least two faces in this zone. This identification is frequently by no means easy even in the case of fair-sized crystals, and becomes exceedingly difficult when the crystal is small and rich in faces; yet the smaller the crystal the better has been its chance of undisturbed growth.

Faces often occur which do not lie exactly in the zone under measurement, but there is no way of accurately determining the deviation from the zone. Further, if several images occur close together, but not in the same zone, it will very probably be impossible to determine the precise position of each.

Since in this method measurements are, as far as possible, always made in zones, the indices of the faces may be readily calculated by means of the law of zonality.

II. *The Two-Circle or Theodolite Goniometer.*

Since we are concerned with the relative and not the absolute position of crystalline faces, we may refer the position of any face to that of a pole on a sphere, and denote it by means of two co-ordinates—the polar distance and azimuth, corresponding to the N.P.D. and R.A. of a star in astronomy. The theodolite goniometer gives at once such co ordinates for any face.

An instrument of this character was employed many years ago (in 1874) by Miller to determine the faces presented by a platinum bead which had been strongly heated before the blowpipe. He merely fixed a goniometer with a vertical circle on another with a horizontal circle. His method and results were published after his death by Prof. W. J. Lewis,[1] but do not seem to have attracted much attention. Rather more than a decade later Prof. V. Goldschmidt[2] described a goniometer with two circles, which is practically the same as Miller's. Almost at the same time Herr Czapski[3] gave a description of his form of goniometer, in which the crystal has motion about a vertical axis, while the telescope and collimator, inclined to one another at a small angle, move about a horizontal axis. Shortly afterwards Prof. Fedorow[4] pointed out that he had in 1889 published in the proceedings[5] of the St. Petersburg Mineralogical Society a description of a two-circle goniometer. This again is, except for the use of an auto-collimating telescope, of the same type as Miller's.

In employing a goniometer of this kind we adjust the face or one of the faces of greatest symmetry accurately parallel to the circle carrying the crystal. For any other face the reading of this circle gives the azimuth, and of the second circle the polar distance, after the subtraction of constants in the two cases, if necessary.

It is evident that the chief difficulty involved in the older method is in

[1] *Proc. Camb. Phil. Soc.*, 1882, IV, 236. Abstract in *Zeits. Kryst. Min.* 1883, VII, 619.

[2] *Zeits. Kryst. Min.* 1893, XXI, 210.

[3] *Zeits. für Instrumentenk.*, 1893, 1.

[4] *Zeits. Kryst. Min.* 1893, XXI, 574.

[5] XXVI, 458. Abstract in French in *Bibliothèque géologique de la Russie*, 1890, VI, 97

this type of instrument entirely overcome. No readjustment of the crystal is required. Each face is observed once only, and the position corresponding to every image is accurately defined.

Did we denote a face by means of these co-ordinates, no exception could be taken to this method. We, however, have to deduce from them the indices of the faces, and this is in general a tedious and troublesome process. Unless a zone includes the face of reference, or its edge is perpendicular to that face, no immediate use can be made of the law of rational indices on which depends the anharmonic ratio of four poles in a zone, and, consequently, Miller's simple logarithmic formulæ cannot be employed. The formulæ devised by Profs. Goldschmidt and Fedorow[1] are cumbersome, and not readily adapted to logarithmic computation.[2]

Further it is impossible to determine without a troublesome calculation whether three faces lie in a zone, unless the zone be one of those mentioned above. Indeed, much of the time saved in the observations is lost in the calculations.

It may be remarked that, if an unknown crystal be measured of which the symmetry is not obvious, the pole of a face of symmetry may not have been chosen as pole of reference, in which case it is exceedingly difficult to identify the crystal.

III. *The Three-Circle Goniometer.*

The advantages of both methods may readily be combined by the addition of a third circle. The crystal is adjusted once for all, and measurements may be made in any desired zone, the orientation of which is at the same time determined.

For crystals small enough to be firmly held by the wax in all positions by far the most convenient arrangement is to give all three motions to

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[1] *Loc. cit.*

[2] *Cf.* the very suggestive remarks by Signor C. Viola, *Zeits. Kryst. Min.*, 1898, XXX, 423:—

"Ich bin der Meinung, dass, sowohl was die Messung der Krystalle, als auch was die Signatur der Flächen anbetrifft, man hauptsächlich auf die Zonen Rücksicht haben muss, denn nur dadurch kann eine Erleichterung herbeigeführt werden, obwohl die meisten Flächen von den Zonen ein wenig abweichen.

"Das Princip der Zonen, oder was gleich ist, das Princip der Rationalität darf nicht bei Seite gelassen werden, wiewohl es in der Natur nicht mit absoluter Strenge zutrifft. Ein solches Princip ist eben der Leitfaden der Krystalle, wie das Newton'sche Gesetz, das auch nicht genau in der Natur gilt, für die Bahnberechnung der Planeten jedoch das Fundament bildet.

"Erfüllt ein Theodolithgoniometer solche Bedingungen nicht, so hat es besseren Instrumenten Platz zu machen."

the crystal, but, if necessary, the telescope and collimator might have one or more.

(*a*) *The Instrument.*

This form of goniometer consists essentially of three circles :—

(A)[1] The horizontal circle,
(B) The vertical circle,
(C) The third circle.

These must be so arranged that the axes of A and C are always at right angles to B, though inclinable at any angle to each other. At the same time the axis of A must be perpendicular to the bisectrix of the angle between the telescope and collimator, and all three axes must, at any rate approximately, intersect in the optic centre.[2]

The last condition must be fulfilled to avoid the necessity for re-centering any but very small crystals during the course of observations. If a collimator be used, re-centering is not essential to the accuracy of the measurements.

The axis of B is adjusted in the same way as for a theodolite goniometer.[3] A face is adjusted parallel to this circle, so that no movement of the reflected image takes place on rotation, and the axis adjusted until this image coincides with the cross-wires. B is now turned about the axis of A through a right angle, and the axis of C is adjusted at right angles to that of B in the same way as the latter axis has been adjusted to that of A.

As an experiment a Fuess Model II goniometer has been converted into this form by the substitution of a two-circle arrangement in place of the original crystal-holder. Plate II, which is reproduced from a photograph of the actual instrument, shows the general construction. Since it is of the utmost importance that all the parts should be absolutely rigid, some more efficient connection between the extra circles and A (retaining the nomenclature used above) is required than that already provided. The horizontal plate of the additional apparatus is rigidly attached by means of three clamps to the rabbet underneath it, which, in its turn, is firmly screwed to A. Underneath this plate is a short cylindrical piece, which fits into the hole already in A and serves to keep

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[1] Throughout this paper reference will be made to the circles by these letters.

[2] The intersection of the axes of the telescope and collimator.

[3] *Vide* Fedorow, *loc. cit.*

the additional apparatus in position when rotating independently of this circle. In this way the reading for a face parallel to B may be made a convenient quantity, such as 0°0′. On the top of the plate is fixed the counterweight, and opposite this the vertical piece carrying the cone of B. This piece has from a side aspect an L-shaped termination, and is attached to the horizontal plate from underneath by four screws. Mechanical means for raising or lowering the axis of B have been omitted, as their provision would have weakened this important junction. This axis may, however, be raised a small amount by packing with paper, which is easily cut to shape and practically incompressible. By slotting the lower holes, through which the screws pass, B may be moved to or from the axis of A; an adjustment required if the axis of C does not, when adjusted in direction, pass through the optic centre. The axis of B has three adjustment screws: two (visible in the figure) to bring it into the horizontal plane, and one (at the back) to make it intersect the axis of A. In the present case it was found to be appreciably too low, and was raised, in the manner described, about 1 mm. The axis of C has also three adjustment screws: two to bring it into a plane parallel to B and one to make it intersect the axis of this circle.[1] It can, if necessary, be made to pass through the optic centre in the manner described above. Both circles have clamps and slow motions and fixed verniers reading to minutes. The circle C for the sake of lightness has been constructed of aluminium; the remainder of the apparatus of bronze. In setting off the graduations on B it was arranged that, where the axis of C is vertical, the reading should be as nearly as possible 0°0′. This condition has not quite been fulfilled. The axes of B and C more nearly intersect when the reading is 0°30′. The extra apparatus is clamped to A in such a position that the reading of this circle for a face parallel to B is exactly 0°0′. The crystal-holder is of the ordinary type, and has the usual adjustments. The counterweight to C and the crystal holder is attached on the other side of B, to prevent any shearing stress on the cones of the latter. Springs are added to keep B and C in position. The circles B and C are about 11 and 9 cm. in diameter respectively. This permits of the former being turned about the axis of A through 190° approximately,[2]

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[1] The latter adjustment may be employed to make the reading of B a convenient quantity when the axis of C is vertical.

[2] That this angle could not be conveniently made larger is one of the disadvantages of adapting an existing goniometer. It might, however, in an instrument entirely new from the beginning be easily arranged that B could be turned round the axis of A through nearly 300°.

when the telescope and collimator are inclined to one another at an angle of 70°, and of the latter through 240° approximately, when the axis of B bisects the interior angle between the telescope and collimator. The tubes of the telescope and collimator are covered with india-rubber, to prevent jarring in the event of either B or C coming into violent contact with them.

(*b*) *How to use the instrument.*

If we adjust the edge of a zone parallel to the axis of C, and rotate the crystal about this axis, we bring in turn all the faces in this zone parallel to B. Rotating A[1] until it reads 0°0′, in which case the image reflected from a face parallel to B is on the cross-wires, and for convenience making the axis of C vertical (though this is not essential), we note the readings when the different faces are parallel to B. If we then proceed to clamp C when some face is in this position and rotate B, we bring any zone containing the face parallel to A, and find the readings of the latter circle for all faces lying in the zone. In other words, we can take two-circle measurements with the pole of any face in a particular zone as pole of reference.

It is, therefore, easy to see that for any zone adjusted by means of B and C parallel to A,

A gives the angles in the zone,

B the angle between this zone and the zone of reference,[2] and

C the pole, whether representing an existing face or not, in which the zones intersect.

Since A can be rotated through 190° at the most, only half a zone can be measured at a time. To complete the zone we must rotate C through 180°, and B back through the zero position till the axis of C makes the same angle with the vertical as before, but on the other side.

In setting up any crystal for measurement we should choose the zone of greatest symmetry as zone of reference; [111] and [010] in the case of hexagonal and monoclinic crystals respectively. In this way, except on triclinic crystals, there will be a possible face parallel to C. By keeping this circle vertical we may take measurements with the pole of the face parallel to it as pole of reference, and thus get a general idea of

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[1] If the axis of C be vertical, this zone may be measured whatever be the reading of A, but it is only when the latter reads 0°0′ that the reading of C for any particular face indicates the position in which it is parallel to B.

[2] The zone whose edge is parallel to the axis of C.

the positions of the faces on the crystal. We can see at once from a stereographic projection in which zones it would be best to take measurements.

Although convenient, it is by no means essential that the zone of reference should be one of symmetry. If an unknown crystal, whose symmetry is not obvious, be measured for identification, the most prominent zone would naturally be chosen for reference, and measurements made to determine the positions of the remaining faces with respect to it.

The extra apparatus has been constructed by Messrs. Troughton and Simms, the well-known opticians and mathematical instrument makers, of London. The author is glad to have this opportunity of putting on record his gratitude to them for the able and careful manner in which they have carried out his ideas.

The following measurements of a crystal of anorthite from Monte Somma have been made with the three-circle goniometer here described, and are added as an example of the readings obtained when a crystal is measured according to this method :—

OBSERVED READINGS.

Zone of Reference [100]			A	B	C	C (from *c*)	Dana.
	1	*c*(00$\bar{1}$)	0° 0′	0°30′	198°32′		
	2	*n*(02$\bar{1}$)	,,	,,	151 47	46°45′	46°46′
	3	*b*(010)	,,	,,	104 31	85 55	85 50
	4	*r*(021)	,,	,,	61 14	42 38	42 38½
	5	*c*(001)	,,	,,	18 36		
	6	*n*(0$\bar{2}$1)	,,	,,	332 5	46 31	46 46
	7	*M*($\bar{1}$10)	290 36	302 10	198 32		69 20
	7	*M*($\bar{1}$10)	62 23	64 45	104 31		62 26½
	8	*z*($\bar{1}$30)	30 54	,,	,,		30 58
	9	*y*($\bar{2}$01)	90 30	99 31	,,		90 32½
	10	*w*($\bar{2}$41)	38 40	,,	,,		38 41½
	11	*p*($\bar{1}$11)	297 45	309 8	,,		62 13
	12	*o*($\bar{1}\bar{1}$1)	64 46	,,	,,		64 53
	11	*p*($\bar{1}$11)	54 16	58 54	18 36		54 17
	9	*y*($\bar{2}$01)	81 8	91 44	,,		81 14
	11	*p*($\bar{1}$11)	315 53½	277 22	61 14		
	9	*y*(201)	275 44½	,,	,,		

The values of the angles given in the last column have been taken from Dana's *System of Mineralogy*, Sixth Edition. Comparison must be made with the readings of A (after subtraction from 360°, if necessary), except in the case of the zone of reference, when the angular values must be compared with those given in the fourth column.

The last two observations were taken to verify the tautozonality of *p*, *y* and *e*.

Note on the Identity of Paralaurionite and Rafaelite.

By G. F. Herbert Smith, B.A.,

Assistant in the Mineral Department of the British Museum.

[Read June 20th, 1899.]

Paralaurionite from Laurium was described by the author in the last number of this Magazine,[1] published early in April of this year, and was so called on account of its chemical composition being, as was shown by Mr G. T. Prior, the same as that of Laurionite. Shortly after, in the number of Groth's *Zeitschrift* published on May 30th, appeared a posthumous paper[2] on new minerals from Chili by the late Professor Arzruni in which was described a new oxychloride of lead, Rafaelite. A comparison of the mean values of the measured angles leaves no doubt as to the identity of the two minerals. The mode of twinning and the optical characters are also the same. The only difference is one of colour: Paralaurionite is white, whereas Rafaelite is violet-red, and shows strong pleochroism. Sufficient material of the latter mineral was not available for quantitative analysis

The following table compares the means of the measured angles:—

Paralaurionite.		Rafaelite.	
	Observed mean.		Observed mean.
100 : 001	62°47′	100 : 001	62°47′
$\bar{1}00 : \bar{1}01$	77 0	$\bar{1}00 : \bar{1}02$	76 46
$\bar{1}00 : \bar{2}01$	45 24	$\bar{1}00 : \bar{1}01$	45 30
$\bar{1}00 : \bar{4}01$	21 34	$\bar{1}00 : \bar{2}01$	21 57
$\bar{1}00 : \bar{6}01$	13 53	$\bar{1}00 : \bar{3}01$	14 7
100 : 110	67 25	100 : 130	67 28
100 : 111	58 28	100 : 132	58 32
001 : 111	52 39	001 : 132	52 40
001 : 110	79 55	001 : 130	79 55

In addition to these the following forms were found on Rafaelite:—($\bar{1}03$), (101), (201), (110), (010), (432). The form (111) of Paralaurionite is (132) of Rafaelite.

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[1] 1899, XII, 108. The axial ratios are there incorrectly stated. They should be $a : b : c = 2{\cdot}7036 : 1 : 1{\cdot}8019$.

[2] *Zeits. Kryst. Min.* 1899, XXXI, 229.

The Identity of Binnite with Tennantite; and the Chemical Composition of Fahlerz.

By G. T. Prior, M.A., F.G.S., and L. J. Spencer, M.A., F.G.S.,
Assistants in the Mineral Department of the British Museum.

[Read January 31st and June 20th, 1899.]

I. Binnite—(*a*) Historical and Introductory; (*b*) Crystallography; (*c*) Physical Characters; (*d*) Associations; (*e*) Chemical Composition; (*f*) Identity of Binnite with Tennantite.

II. Chemical Composition of Fahlerz.

(*a*) Historical and Introductory.
(*b*) Tetrahedrite from "Fresney d'Oisans, Dauphiné."
(*c*) Tetrahedrite from Horhausen, Rhenish Prussia.
(*d*) Tetrahedrite from (Wolfach, Baden)?
(*e*) Proposed new formula for Fahlerz.
(*f*) Test of new formula by reference to the results of previous analyses.

I. Binnite.

(*a*) *Historical and Introductory.*

FEW minerals have had a more varied career than the cubic sulpharsenite of copper—the binnite of Des Cloizeaux—which as small brilliant crystals is of rare occurrence in the white saccharoidal dolomite of the Binnenthal in Switzerland.

Damour,[1] who first mentioned the crystals, gave the locality incorrectly as St. Gotthard, and supposed them to be the same material as the associated massive sulpharsenite of lead ($2PbS.As_2S_3$), which he analysed and called dufrenoysite. According to Damour's paper the crystals had been previously known as grey copper, and that they were thus early correctly identified it is the object of the present paper to prove. Owing to Damour's mistake there has been much confusion in the names binnite

[1] "Notice sur le sulfo-arséniure de plomb de Mont Saint-Gothard (Nouvelle espèce minérale)". *Annales de Chimie et de Physique*, 1845, [iii], XIV, 379-383.

and dufrenoysite, and both of them have been applied to each of the two minerals mentioned above; while, owing to the difficulty of distinguishing the several sulpharsenites of lead from the Binnenthal, the name binnite has had at various times at least four different meanings.[1] The distinctive names cuprobinnite and plumbobinnite, introduced by Weisbach,[2] have not been generally followed. It may be mentioned here that the other cubic minerals, galena and blende, from the Binnenthal dolomite have sometimes been mistaken for binnite.

The following three analyses have been made of the cubic copper mineral (binnite); they were in all probability made on very small amounts of material, though in only one case is the actual weight given, namely, 0·0785 gram (Stockar-Escher).

	Uhrlaub.[3]	Stockar-Escher.[4]	Macivor.[5]
Cu	37·74	46·24	46·05
Ag	1·23	1·91	2·43
Fe	0·82	—	—
Pb	2·75	—	—
As	30·06	18·98	18·79
S	27·55	32·73	32·46
	100·15	99·86	99·73
Sp. gr.	4·35—4·69		5·52

From these analyses the following formulæ have been deduced :—

$Cu_2S.CuS.As_2S_2$	S. v. Waltershausen, from Uhrlaub's analysis.
$3Cu_2S.2As_2S_3$	Rammelsberg (1860) ,, ,,
$3Cu_2S.As_2S_3$	Kenngott, from Stockar-Escher's analysis.
$4CuS.Cu_2S.As_2S_3$	Rammelsberg ,, ,,
$3Cu_2S.As_2S_3$	Petersen (*l. c.*) ,, ,,

Of these formulæ, the second, $3Cu_2S.2As_2S_3$, as deduced from the earliest analysis, is the one usually adopted in the text-books, while the two later and more correct analyses are only mentioned.

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[1] Heusser, *Pogg. Ann.* 1855, XCIV, 334. Des Cloizeaux, *Annales des Mines*, 1885, [vi], VIII, 398. Kenngott, *Min. d. Schweiz*, 1866, 373. Petersen, *Ber. Offenbacher Ver. f. Naturk.* 1866, VII, 131.

[2] *Char. Min.* 1880, p. 42.

Sartorius von Waltershausen, *Pogg. Ann.* 1855, XCIV, 120.

[4] Kenngott's *Uebersicht* for 1856-7, 1859, p. 174.

[5] *Chem. News*, 1874, XXX, 103. Small amounts of lead and iron were deducted.

These differences are only to be explained by defective analyses made on very small amounts of material, though Trechmann suggested that they might be due to the existence of two cubic copper minerals, the one holohedral and the other tetrahedral. The question as to the holohedral or tetrahedral character of binnite was at one time the subject of much discussion,[1] and it has only recently been decided by Baumhauer[2] and Trechmann[3] that the mineral is really tetrahedral.

The combined crystallographic and chemical results to be described in the present paper show that this much misrepresented mineral, binnite, is nothing more nor less than the arsenical variety of the common fahlerz, and that, except in the more perfect development of the crystals, it does not differ from Cornish tennantite.

The close relationship between binnite and tennantite has been pointed out before. Des Cloizeaux (*loc. cit.*) described binnite as a very arsenical variety of tennantite, but gave the characters which, in his opinion, served to distinguish the two minerals; while Delafosse, in his *Cours de Minéralogie* (1860), actually placed binnite under arsenical grey copper, and pointed out that, according to Stockar-Escher's analysis, it has the composition of Cornish tennantite.

(*b*) *Crystallography.*

Previous descriptions of binnite have been based on only a few crystals, sometimes only one. The present description, which however adds very little to those of Baumhauer and Trechmann, is based on the examination of about 60 crystals and the goniometric measurement of 24 crystals and 28 fragments. A large part of this material was collected by Mr. R. H. Solly during blasting operations in the Binnenthal in the summer of 1898.

Crystals of binnite are brilliant in appearance, and most of the faces are very bright and smooth. In size they rarely exceed 3 or 4 mm. in diameter; the largest crystal, which is slightly elongated in the direction of the trigonal axis, is nearly 1 cm. long. They are rich in faces, and two or more forms are usually more or less equally developed (Fig. 1), so that the crystals are rarely distinctly cubic or dodecahedral in habit, whilst only one crystal exhibited a tetrahedral habit. Frequently

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[1] Heusser (1856), Sartorius von Waltershausen (1857), Kenngott (1859), Schrauf (1873), Hessenberg (1875), Lewis (1878), Groth (1878).

[2] "Deutliche hemiëdrische Binnitkrystalle," *Zeits. Kryst. Min.* 1893, XXI, 202–207; *Ibid.* 1897, XXVIII, 545–551.

[3] *Min. Mag.* 1893, X, 220–228.

the crystals are very irregularly developed, and without removing them from the matrix they are often difficult to decipher unless certain faces can be identified by the characteristic striations and etchings. Even when the crystals are detached they often cannot be properly orientated until two or three zones have been measured on the goniometer, since there is an equality[1] in several of the angles, *e.g.* 100 : 211 = 111 : 110 = 111 : 114 = 35°16′. Usually the crystals occur singly, but sometimes two are grown together in very nearly parallel position. No twinning could be made out.

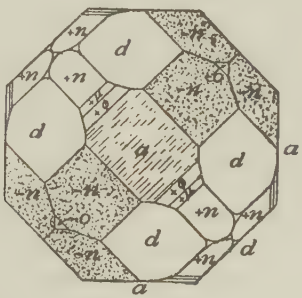

Fig. 1.

The following forms[2] were identified on the 24 crystals measured on the goniometer :—

a {100}. This is present on all crystals either as large or small faces ; these are always bright, and are smooth or faintly striated parallel to their intersection with *o*(111) in the first or positive octant.

d {110}. This is present on all crystals usually as a prominent form. The faces are bright and smooth, and only rarely etched and striated parallel to their intersection with the adjacent cube faces.

+*o* {111}. Small and bright; not common. On the single crystal, which is tetrahedral in habit, it is present as a large face striated parallel to its intersections with the cube planes.

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[1] *See* A. Schmidt, "Wiederkehr gleicher Flächenwinkel im regulären Krystallsysteme," *Zeits. Kryst. Min.* 1896, XXV, 477; and *Math. és term.-tud. Értesitő*, 1895, XIII, 331.

[2] The letters used for the forms are those of Dana (*System of Min.* 1892, 6th Edit.).

$-o\{1\bar{1}1\}$. This is more frequently present than $+\{111\}$. The faces are small and bright, and often appear to have been developed by the etching of $-n\{2\bar{1}1\}$.

$+n\{211\}$. Is present on all crystals, and is often a prominent form. It is very bright and smooth, but is sometimes faintly striated parallel to its intersection with $+o\{111\}$, especially when several other $\{hkk\}$ forms are present in the same octant.

$-n\{2\bar{1}1\}$. Is also present on all crystals either as large or as narrow planes. Usually the faces, though quite even, are dull and like ground-glass in character, giving no reflected image. Rarely they are bright and smooth, or with a slight reddish tarnish. Sometimes the pittings are deep, and light is then seen to be reflected from numerous spots in the position of $-o\{1\bar{1}1\}$, and, to a lesser extent, of $d\{110\}$ and $a\{100\}$.

$+\phi\{611\}$. A small bright face striated parallel to its intersection with the cube; present on most crystals, sometimes rather large.

$+\{hkk\}$. Some crystals show in the positive octants banded zones of bright narrow faces between the cube and octahedron; they are striated and sometimes rounded parallel to their intersections with these faces. The following angles are a selection of the best of the numerous ones measured on the several crystals, the reflections being from distinct planes:—

$+\{hkk\}$.	Calcd. to (100).	Measd. (L.J.S.).	(Observers.)[1]
25.1.1	3°14′	3°18′. Large smooth plane.	—
18.1.1	4 29½	4 28, 4°30′. On two crystals.	—
14.1.1?	5 46	5 40.	—
12.1.1	6 43	6 40, 6°37′.	(Baumhauer, T.).
51.5.5	7 53½	7 53. Fairly large.	—
10.1.1	8 3	8 2, 8°11′.	(Hessenberg, L.T.B.).
911	8 56	8 54.	(Trechmann).
811?	10 1½	9 46, 10°21′.	,,
31.4.4	10 20½	10 21.	—
711	11 25	11 25, 11°29′.	(Lewis, T.B.).
611	13 16	13 15, etc.	(Heusser, Groth, L.B.T.).
411	19 28	19 24, 19°28′, 19°16′, 19°21′.	(Hessenberg, L.B.T.).
311	25 14	25 13, 25°23′, 25°12′.	(Trechmann, B.).
522	29 30	29 18.	(Trechmann).
25.12.12	34 10	34 11½.	—
211	35 16	35 16, etc.	(All authors).

[1] T = Trechmann; L = Lewis; B = Baumhauer.

$+r\{332\}$. Small bright faces striated or rounded parallel to the edges $[n, n]$, which they truncate. On five crystals.

$-r\{3\bar{3}2\}$. Small dull faces of the same character as $-n\{2\bar{1}1\}$, the edges of which they truncate; striated parallel to their intersection with $-o\{1\bar{1}1\}$, *i.e.* perpendicular to the edge $[-n, -n]$. On five crystals, but not on those with $+r\{332\}$.

$+\Sigma\{552\}$. Small bright faces, sometimes striated and rounded parallel to their intersections with $+o\{111\}$. On four crystals. Besides those from $+r$ and $+\Sigma$, there are other scattered reflections in the zone between (111) and (110) in the rounded positive octants.

$e\{210\}$. } As bright narrow roundings on the edges formed by the
$f\{310\}$. } cube and the dodecahedron. {210} is new for "binnite."

$+s\{321\}$. As a small bright face striated parallel to its intersection with $+o\{111\}$. More often as a narrow rounding on the edge [211, 110].

$+G\{543\}$. } Several small bright planes with curved contours in the
$+\{965\}$. } smooth rounded area in the positive octant of one crystal. The faces (211), (965), (543), (332), (453), (695), (121) form a zone. These two forms are new for fahlerz.

	Calc^{d}.	Meas^{d}. (L.J.S.)
543 : 453	11°28½′	11°32′, 11°28′, 11°32′.
965 : 695	20 51	20 12.
965 : 332	10 15½	10 10, 10°0′.

From the characters given above, it will be seen that there are several indications of the tetrahedral symmetry, namely:—

(1). The striation of the cube planes parallel to their intersections with the positive tetrahedron.

(2). The faces of $+n\{211\}$ and $+r\{332\}$ are bright and smooth in the positive octants, whilst the complementary forms $-n\{2\bar{1}1\}$ and $-r\{3\bar{3}2\}$ are usually dull and rough.

(3). The development in the positive octants of numerous $\{hkk\}$ forms.

(4). Hexakistetrahedral forms $\{hkl\}$ occur in the positive octants. Baumhauer's $\{9\bar{4}1\}$ is the only one in the negative octant.

(5). The bright roundings of the edges and coigns in the positive octants, which are sometimes so pronounced that the whole area has the appearance of a polished knob. Only rarely are the crystals rounded in the negative octants.

These points are shown diagrammatically in Fig. 1.[1] It is to be noticed that the hemihedral character is not often apparent from the relative sizes and development of the faces in adjacent octants, and as a rule it seems only to have been brought out by the subsequent etching of the crystals. Thus on some crystals $+n\{211\}$ and $-n\{2\bar{1}1\}$ are of the same size, and are equally bright and smooth, so that the symmetry is apparently holohedral. The effect of the etching has been to roughen the faces in the negative octants, and to round the edges and coigns with bright prærosion[2] planes in the positive octants. Many of the small faces noted above may be only due to prærosion.

It should be pointed out that the indications of the hemihedrism given above do not as a rule apply to fahlerz from other localities, as for example those described in Sections II. (*b*)—(*d*) below, and that the distinction between positive and negative forms is purely arbitrary, and cannot be compared for different occurrences.

(*c*) *Physical Characters.*

The colour is iron-black, with a brilliant metallic lustre and an almost velvety appearance. The streak (on paper) is dull and is usually chestnut-brown, but it varies in shade for different crystals, and is sometimes dark brown with a tinge of purple, whilst for two crystals it is black. In the first case the streak on the crystals is cherry-red, and the fine powder is dark purple. Very thin splinters of the crystals with the chestnut-brown streak are translucent and crimson by transmitted light, and crimson flashes may sometimes be seen on the fractured surfaces. The mineral is optically isotropic. Crystals with the black streak are opaque. The colour of the streak appears to depend on the amount of iron in the mineral (p. 192).

A marked feature is the very good and brilliant conchoidal fracture. The mineral is very brittle. H.=4½. Sp. gr. (weight of 1 c.c.) of the material analysed is 4·62 at 18° (as determined on 0·4878 gram) for the crystals with the chestnut-brown streak, and 4·598 for those with the black streak.

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[1] This is much the same as Baumhauer's Fig. 9, Plate IX, in *Zeits. Kryst. Min.* 1897, XXVIII.

[2] A. Hamberg, *Bihang Svenska Vet.-Akad. Handl.* 1887, XIII (2), No. 4; Abstract in *Zeits. Kryst. Min.* 1889, XV, 84.

(*d*) *Associations.*

Usually the crystals of binnite occur singly, though sometimes there are as many as a dozen crystals in the same cavity. They seem to be most frequent in those parts of the white saccharoidal dolomite which are veined with coarsely crystalline yellowish dolomite. The crystals rest on the colourless crystallised dolomite lining the cavities, or sometimes on crystals of blende. In one case the crystals of blende and binnite were in very nearly parallel position. Small crystals of pyrites encrust and are partly embedded in the binnite. Sartorite and realgar are frequently present.

(*e*) *Chemical Composition.*

The first of the following two analyses was made on eleven of the measured binnite crystals, of which the streak was chestnut-brown. The crystals were broken up, and the fragments carefully selected. The method of analysis was by decomposition in chlorine, as described in the case of andorite.[1] The arsenic was determined in the solution of the volatile chlorides by precipitation with magnesia mixture. The chlorine appeared to have very little action upon the mineral in the cold. The results of the analysis[2] made on 0·3101 gram were as follows (G. T. P.):

			Atomic ratios.	
Cu	...	49·88	·7895	6
Ag	...	1·87	·0174	
As	...	19·04	·2558	1·902
Pb	...	0·17	·0008	0·006
Fe	...	1·11	·0200	0·148
S	...	27·60[3]	·8671	6·446
		99·62		
Sp. gr.	...	4·62		

The numbers correspond approximately to the formula :—

$$3Cu_2S.As_2S_3 = Cu_3AsS_3.$$

The sulphur is somewhat too high, the atomic ratio calculated to convert the other elements into sulphides being as low as 0·8080.

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[1] *Min. Mag.* 1897, XI, 290.

[2] The atomic weights used throughout this paper are those given by F. W. Clarke (*Smithsonian Miscell. Collections*, 1897, No. 1075).

[3] Mean of 27·56 and 27·65, the latter by fusing another portion (0·1972 gram) of the same sample of material with sodium carbonate and potassium nitrate.

A second partial analysis was made on two crystals, of which the streak was black instead of chestnut-brown, in order to discover, if possible, on what this difference of streak depended. The results of the analysis made on 0·1390 gram were (G. T. P.):—

			Atomic ratios.	
Cu	...	44·12	·6991	6
Ag	...	4·77	·0445	
As	...	[20·49]	·2690	2·171
Fe	...	3·68	·0662	0·534
S	...	26·94	·8463	6·830
		100·00		
Sp. gr.	...	4·598		

The numbers correspond closely to the formula:—

$$[3(Cu,Ag)_2S.As_2S_3]+\tfrac{1}{12}[6FeS.As_2S_3].$$

The results of this analysis, when considered in connection with Rose's analyses of fahlerz (see pp. 204-6), and the three tetrahedrite analyses given in the present paper, suggest that the black streak is due to the presence of iron in larger amount than three per cent., and that the red streak has no connection with the amount of silver (as implied in Dana's *System of Mineralogy*) or with the amount of zinc (as stated in Naumann-Zirkel's *Mineralogie*).

(*f*) *Identity of Binnite and Tennantite.*

The crystallographic and chemical investigation of binnite, the details of which are given in the preceding paragraphs, shows that neither physically nor chemically is there any essential difference between binnite and tennantite.

The crystals of the Binnenthal mineral possess the same degree of symmetry as the Cornish tennantite, and only differ in their more perfect development, being brighter and richer in faces. W. Phillips,[1] who first described tennantite in 1819, gave the forms: $a\{100\}$, $d\{110\}$, $o\{111\}$, $n\{211\}$ and $\beta\{322\}$; and in the MS. catalogue (by Prof. Miers) of the specimens of Cornish tennantite in the British Museum collection the forms are: $a\{100\}$, $d\{110\}$, $+o\{111\}$, $-o\{1\bar{1}1\}$, $+n\{211\}$, $-n\{2\bar{1}1\}$, $+r\{332\}$, and narrow planes near $+\phi\{611\}$. All these forms occur on crystals of binnite.

[1] *Quart. Journ. Lit. Sci. & Arts* (*Roy. Inst.*), 1819, VII, 95; and Phillips' *Min.* 1823, 3rd Edit.

The dull crystals of Cornish tennantite are usually much intergrown with each other and with other minerals, so that they do not show the same bright lustre and perfect conchoidal fracture as binnite. Otherwise the physical characters are the same: thus Cornish tennantite has sp. gr.[1]=4·69 and H=4, and shows the same variation in the colour of the streak from dark red to black.

That they are also chemically identical is seen by comparison of the above analyses (pp. 191-2) with the following three analyses of Cornish tennantite:—

	Kudernatsch.[2]	Rammelsberg.[3]	Wackernagel.[3]	$3Cu_2S.As_2S_3$.	$4Cu_2S.As_2S_3$.
Cu	48·94	51·62	48·68	52·70	57·60
As	19·10	19·03	20·53	20·72	16·98
Fe	3·57	1·95	3·09	—	—
S	27·76	26·61	26·88	26·58	25·42
	99·37	99·21	99·18	100·00	100·00
Sp. gr.	—	—	4·69	—	—

II. Chemical Composition of Fahlerz.

(*a*) *Introduction.*

The chemical formula generally accepted for fahlerz (tetrahedrite and tennantite) and given in the text-books is $4Cu_2S.(Sb,As)_2S_3$, or generally $4R''S.R'''_2S_3$, where $R''=Cu_2,Ag_2,Fe,Zn$, &c., and $R'''=Sb,As,Bi$; the divalent atoms Fe,Zn being supposed to isomorphously replace Cu_2. This is the formula which was originally proposed by H. Rose in 1829, as best expressing the result of seven analyses of fahlerz from various localities made on pure crystallised material.

Very few, however, of the published analyses of fahlerz agree at all closely with this formula, and many of them approach much more nearly to the 3 : 1 formula $3R''S.R'''_2S_3$. One of the latest analyses of tetrahedrite (see analysis 18, p. 213) corresponds to the formula $7RS.2Sb_2S_3$ or $4RS.Sb_2S_3+3RS.Sb_2S_3$. This want of agreement of most of the analyses with the ordinary text-book formula has received expression in the latest

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[1] Wackernagel (1860) and Baumert (1858).

[2] *Pogg. Ann.* 1836, XXXVIII, 397.

[3] Rammelsberg's *Handb. d. Min.-Chem.* 1860, p. 88. Other analyses of Cornish tennantite are given by R. Phillips (1819), Hemming (*Phil. Mag.* 1831, X, 157), and vom Rath and Baumert (*Sitz.-ber. niederrh. Ges. Bonn*, 1858, XV, p. LXXII).

supplement (1895) to Rammelsberg's *Mineralchemie*, where the composition of fahlerz is given as a mixture of $3RS.Sb_2S$ and $4RS.Sb_2S_3$.

It will be found as a general rule that the analyses which approach most closely to the ordinary 4 : 1 formula are those in which the percentages of divalent elements (Fe,Zn) are high. On the other hand, whenever an analysis shows a comparatively simple composition, with only small percentages of divalent elements, the numbers correspond very closely to the 3 : 1 formula. This is the case with the first analysis of binnite (p. 191), and also with the analyses of Cornish tennantite, quoted on p. 193, as is seen by comparing the numbers with those corresponding to the two formulæ $3Cu_2S,As_2S_3$ and $4Cu_2S.As_2S_3$ given on p. 193. Kudernatsch was only able to make his analysis (p. 193 above) accord with the 4 : 1 formula by considering part of the copper to be present as CuS instead of Cu_2S.

The tennantite from Rudelstadt, Silesia, of which the analysis (No. 10, p. 209) corresponds to the 3 : 1 formula, was on that account described by Websky as a new species under the name of "julianite." "Annivite," "studerite," and the more recent "falkenhaynite"[1] are other names which have been applied to fahlerz, of which the analyses accord more nearly with the 3 : 1 than with the ordinary text-book formula. In some of the text-books many of these are referred to the obscure orthorhombic (?) mineral stylotype, to which the formula $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$ has been assigned.

In the case of tetrahedrite proper the percentage of iron or zinc seldom sinks below 3. An analysis (No. 11, p. 209), however, by Nilson, of the so-called "aphthonite" from Gärdsjö, Wermland, shows only fractional percentages of both iron and zinc. As shown on p. 209, the numbers obtained in this analysis agree almost perfectly with the 3 : 1 formula.

There is thus strong evidence in favour of the view that the true formula for the simple sulphantimonite or sulpharsenite of copper is $3Cu_2S.(Sb,As)_2S_3$. The iron and zinc appear to be the disturbing elements which cause the analyses to approach the 4 : 1 formula of Rose.

In 1870 Petersen, in a short note on the formula of sulpho-salts,[2] actually proposes the 3 : 1 formula for fahlerz, and suggests that variations from this are due to the presence of impurities such as iron- and copper-pyrites in the material analysed. The well-known intimate asso-

[1] Scharizer, *Jahrb. geol. Reichs.* 1890, XL, 433.

[2] *Neues Jahrb. f. Min.* 1870, 455–9.

ciation and parallel intergrowth of copper-pyrites and blende with tetrahedrite, as described by Sadebeck, Becke and others, lend some support to this view. The frequent occurrences of tetrahedrite in which the fracture is granular and interrupted, instead of being perfectly smooth and conchoidal, also suggests that most crystals are not homogeneous, but that they are intimately intergrown with copper pyrites, which indeed can in many cases be seen as minute yellow specks throughout the whole material. In choosing specimens for the present analyses, very few were found which were at all suitable for the collecting of pure material.

The idea, however, that the iron in fahlerz is due to impurities of iron- or copper-pyrites is not supported by an examination of the hitherto published analyses. Calculations of the atomic ratios show that, as a rule, the total sulphur found corresponds with the amount calculated to convert the other elements into sulphides, the iron being supposed to be present as FeS and not as FeS_2.

That the sulphides of the divalent metals might be present in fahlerz in another form of combination with the sulphides of antimony and arsenic than the sulphides of the monovalent metals has been advocated by Kenngott in an elaborate paper on the formula of fahlerz.[1] As the result of his calculations of a large number of analyses he was led to propose the general formula $4R'_2S.R'''_2S_3+x[3R''S.R'''_2S_3]$. He obtained this result, however, by starting with the assumption that the correct formula for the simple mineral was $4Cu_2S.(Sb,As)_2S_3$, and by referring analyses which gave the 3 : 1 formula to "julianite," which he regarded as a distinct species.

In this state of uncertainty as to the true formula of fahlerz, the present investigation was undertaken in order to see if the analysis of pure tetrahedrite of simple composition would confirm the result obtained in the case of binnite, and substantiate the 3 : 1 in preference to the generally accepted 4 : 1 formula ; and to discover, if possible, in the case of specimens of more complex character, in what way the iron and zinc enter into the composition of the mineral.

Three specimens from different localities were selected for analysis. These were chosen on account of their comparative freedom from impurities, such as iron- and copper-pyrites, and the apparent homogeneity of the crystals as indicated by the perfectly smooth and brilliant conchoidal fracture. This latter character was the one chiefly relied upon as a guarantee of purity. In the analyses only crystal fragments showing an

[1] Kenngott. "Ueber die Fahlerzformel." *Neues Jahrb. f. Min.* 1881, II, 228-248.

uninterrupted conchoidal fracture were used. The greatest care was taken in selecting material absolutely free from all visible impurities, each fragment being picked out under the lens and then examined under a microscope, the 1in. objective of which was fitted with a Lieberkuhn.

(*b*) *Tetrahedrite from "Fresney d'Oisans, Dauphiné."*[1]

This specimen is described in the Heuland sale catalogue for May 3rd, 1833, as: "895. An UNIQUE specimen of grey Copper Ore from Fresney, Oisans, Dauphiné, with Rock-crystals and Carbonate of Iron."

On the matrix is a fine isolated crystal, measuring 4 cm. along the octahedral edge, which is by far the largest and best in the large suite of tetrahedrites in the British Museum collection.

Crystallography.—The two tetrahedra $+o\{111\}$ and $-o\{1\bar{1}\bar{1}\}$ are equally developed, so that the crystal has the appearance of a regular octahedron (Fig. 2); but while $+o\{111\}$ is bright and smooth, the com-

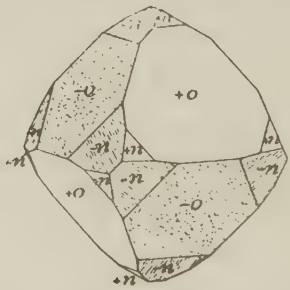

FIG. 2.

plementary tetrahedron $-o\{1\bar{1}\bar{1}\}$ is dull and rough, being covered with numerous minute triangular pyramids reflecting light with the planes of the rhombic dodecahedron. The only reflections in the positions of the faces of $-o\{1\bar{1}\bar{1}\}$ are from the small triangular truncations of these pyramids; these small planes are smooth, but rather dull. The two triakistetrahedra, $+n\{211\}$ and $-n\{2\bar{1}\bar{1}\}$, are well developed; the former is bright and smooth, and very faintly striated parallel to its intersection with the positive tetrahedron; the latter, which is slightly larger, is dull

[1] The authority for this locality is the Heuland catalogue. Two other specimens of tetrahedrite from the Heuland collection, and now in the British Museum, which are exactly similar in appearance and matrix to the specimen now described, are, according to the Heuland catalogue, from Baigorry, Basses-Pyrénées. The latter occurrence is mentioned by Romé de l'Isle (1773), and is described at length by Prof. Lacroix (*Min. de France*, 1897, II, p. 724). Lacroix only just mentions Museum specimens of tetrahedrite as being labelled Fresney d'Oisans.

and deeply striated perpendicular to its intersection with the negative tetrahedron, *i.e.* parallel to its intersection with the rhombic dodecahedron. The rhombic dodecahedron is represented by bright narrow planes truncating the edges $[+o, -o]$, or oscillating with $-n\{2\bar{1}1\}$ and giving rise to the striations on these faces. With the contact goniometer the angle $on = 111 : 211$ was measured as 20° (calculated 19°28′).

Physical Characters.—The colour is steel-grey, with bright metallic lustre; the streak is dull and dark brown, with a tinge of purple. The mineral is opaque, even in thin splinters. Fracture conchoidal, and very bright and smooth. Very brittle; H = 4½. Specific gravity of the material analysed 4·921 at 17°.

Associations.—Although the crystal is in places slightly cracked and etched, yet the material is perfectly fresh in appearance. The cracks are filled with films of limonite together with a little malachite and chessylite, and these substances are in places present as films on the surface of the crystal. On the fractured surfaces of the crystal are one or two yellow marks which seem to be films of copper- or iron-pyrites.

The matrix consists mainly of large rhombohedra of chalybite altered to limonite. On this is the large crystal of tetrahedrite, with a small crystal and a little massive tetrahedrite. Of later formation than this are clear colourless prisms of quartz. All these minerals are coated in places with limonite, and this in turn is coated with thin crusts of green malachite and blue crystalline chessylite. After the deposition of: (1) chalybite, (2) tetrahedrite, and (3) quartz, the material seems to have been slightly crushed and the chalybite altered to limonite, followed by an etching and slight surface alteration of the tetrahedrite.

Chemical Composition.—Plenty of pure material for analysis could be collected without difficulty from the fractured surface of the large crystal. Before being picked over, the fragments were boiled in hydrochloric acid to remove limonite and copper carbonates.

The result of the analysis was as follows (G. T. P.):—

			Atomic ratios.		Calcd. for $3Cu_2S.Sb_2S_3$.
Cu	...	45·39	·7192	6	46·83
Sb	...	28·85	·2414	2·017	29·55
As	...	trace			—
Fe	...	1·32	·0238	·199	—
Pb	...	0·11	·0005	·004	—
S	...	24·48	·7690	6·424	23·62
		100·15			100·00
Sp. gr.	...	4·921			

Weight of material used in analysis = 0·6395 gram and (for separate sulphur determination) 0·3672 gram. The atomic ratio of the total sulphur calculated for the sulphides on the assumption that the iron is present as iron-pyrites is ·7698.

Deducting the iron and lead as FeS_2 and PbS, the atomic ratios for Cu : Sb : S = 6 : 2·017 : 6·022, which correspond almost exactly to the formula $3Cu_2S.Sb_2S_3 = Cu_3SbS_3$.

(*c*) *Tetrahedrite from Horhausen, Rhenish Prussia.*

The beautiful crystals of tetrahedrite from Horhausen in Rhenish Prussia have been described[1] several times, but the material from this locality does not appear to have been analysed. Since the crystals are so perfectly developed, have a good conchoidal fracture, and are not intimately associated with copper-pyrites, they appeared to form suitable material for establishing the tetrahedrite formula. The specimen selected for detailed examination was the one showing the least amount of blende and no copper-pyrites on the free surface.

Crystallography.—The brilliant crystals have all their faces bright and smooth; they measure up to 5 mm. across, but are usually much smaller.

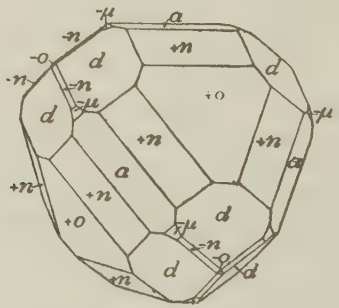

Fig. 3.

The habit of the crystals is tetrahedral, with large faces of the rhombic dodecahedron (Fig. 3). The forms present on six measured crystals giving excellent readings are, in order of predominance :—

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[1] C. Klein, *Neues Jahrb. f. Min.* 1871, 493. A. Sadebeck, *Zeits. Deutsch. geol. Ges.* 1872, XXIV, 458. G. Seligmann, *Zeits. Kryst. Min.* 1877, I, 335. G. vom Rath, *Zeits. Kryst. Min.* 1881, V, 258. P. Groth, *Min.-Sammlung, Strassburg* 1878, p. 66.

$+o\{111\}$. This is usually smooth, but is sometimes represented by bright vicinal faces $\{hhl\}$ $(h > l)$ deeply striated parallel to their intersections with *o* and *d*.

$d\{110\}$. Bright and smooth.

$+n\{211\}$. Bright and smooth.

$a\{100\}$. Bright and smooth. Faintly striated parallel to its intersection with $+o\{111\}$.

$-u\{2\bar{1}1\}$. Narrow; not so bright as $+n$, and sometimes rather rough.

$-\mu\{4\bar{1}1\}$. Bright and smooth; small.

$-o\{1\bar{1}1\}$. Bright and smooth; very small.

$+\mu\{411\}$. Observed once as a narrow plane.

$-r\{33\bar{2}\}$. Observed once as a very narrow rounding between two planes of $-u\{2\bar{1}1\}$.

The above forms, with the exception of the last two, are present on all crystals, and there is very little variation in the relative sizes of the faces on different crystals. The crystals are sometimes grouped together in more or less parallel position, or small crystals are partly embedded in large ones, but no definite orientation between two crystals could be discovered.

There is no marked difference between the surface characters of the faces in adjacent octants, nor could any difference be developed in attempts to etch the crystals with bromine water or with nitric acid.

Physical Characters.—The colour is iron-black, with brilliant metallic lustre. Streak dark brown with a purplish tinge. Only the thinnest flakes are crimson by transmitted light; the mineral is then seen to be optically isotropic. Fracture conchoidal, bright and smooth, but not quite so good as that of binnite; where the crystals are intergrown close to the matrix the fracture is only sub-conchoidal. Brittle; H = $4\frac{1}{4}$. Sp. gr. of the material analysed 4·969 at 17°.

Associations.—The matrix consists of massive buff-coloured chalybite with milky quartz in veins and patches; it encloses a few specks of copper pyrites and of a black mineral which is probably massive tetrahedrite. On the free surface are the following crystallised minerals in the order of formation: (1) Lenticular crystals of chalybite with one or two quartz crystals. (2) Galena in dull well-developed octahedra, with small cube planes. (3) Tetrahedrite, which has grown over, and is intimately associated with, the galena. (4) A few small crystals of reddish-brown blende.

Chemical Composition.—The material collected for analysis was boiled with strong hydrochloric acid to remove galena before being picked out under the lens and microscope.

The result of the analysis is as follows (G. T. P.) :—

			Atomic ratios.	
Cu	...	41·55	·6582	6
Sb	...	28·32	·2370	2·20
Bi	..	0·83	·0046	
As	...	trace		
Fe	...	1·02	·0184	0·55
Zn	...	2·63	·0405	
Pb	...	0·62	·0030	
S	...	24·33	·7642	6·95
		99·30		
Sp. gr.	...	4·969		

Weight of material used in analysis 0·4856 gram and (for separate sulphur determination) 0·2808 gram.

The calculated atomic ratio of the total sulphur, assuming iron present as FeS, is ·7530. After deducting $3Cu_2S.Sb_2S_3$, the atomic ratios of the residue are—

$$Sb : (Fe,Zn) : S = \cdot 2 : \cdot 55 : \cdot 95,$$

which correspond approximately to the formula $6(Fe,Zn)S.Sb_2S_3$. The correspondence would have been closer but for a slight loss of zinc during the filtering of the sulphide. The combined formula is therefore :

$$[3Cu_2S.Sb_2S_3] + \tfrac{1}{10}[6(Fe,Zn)S.Sb_2S_3].$$

(*d*) *Tetrahedrite from (Wolfach, Baden)*[1] *?*

Crystallography.—The crystals are tetrahedral in habit (Fig. 4), with large $+o\{111\}$, and smaller $+n\{211\}$, $+\mu\{411\}$ and $a\{100\}$; and on the acute trigonal coigns very small bright $-o\{1\bar{1}1\}$ and $d\{110\}$. The faces of $a\{100\}$ and $+\mu\{411\}$ are deeply striated parallel to their mutual inter-

[1] This specimen has been for many years in the British Museum collection, and was labelled "Andreasberg, Harz" by the late Mr. T. Davies, but the associations are so unlike those described in the literature of minerals from the Harz (Luedecke, *Min. d. Harzes*, 1896) that this locality must be considered as doubtful. On the other hand, on account of the remarkable agreement in every particular with Sandberger's (*Neues Jahrb. f. Min.* 1869, pp. 301, 297; *Untersuch. über Erzgänge*, 1885, II, pp. 288, 283) description of tetrahedrite from the Wenzel Mine near Wolfach in Baden, we have ventured to suggest that the specimen in all probability came from this locality.

sections, while the striations on $+n\{211\}$ in the same direction are much less marked. The faces are bright, but are roughened by curious granular and vermiform markings, so that they give poor reflections; besides these minute markings, there are a few larger thread-like elevations, which

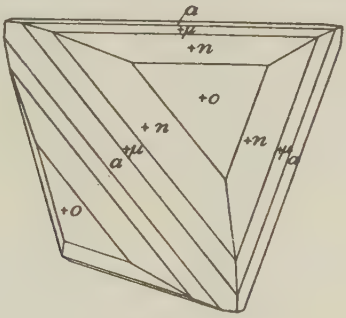

Fig. 4.

often run across from one crystal to another; these suggest healed-up cracks in the crystals. All the crystals are of exactly the same habit and easy to decipher, so that only one was measured on the goniometer. In size the crystals average about 0·5 cm. along the tetrahedral edge, the largest being 1·5 cm.

Physical Characters.—The colour is steel-grey to iron-black, and the streak black (or very dark brown); opaque. Brittle; H=4. The fracture is conchoidal, but in places sub-conchoidal to uneven, especially where the crystals are much intergrown close to the matrix.

Sp. gr. of the material analysed 5·047 at 22°.

Associations.—The matrix is a dirty yellow mixture of dolomite and a scaly talcose mineral, enclosing one or two crystals of pyrites and quartz and some massive tetrahedrite (?). On the free surfaces are two or three crystals of galena (cubo-octohedra with small $d\{110\}$) intimately associated with the crystals of tetrahedrite, and apparently formed at the same time. These crystals are partially embedded in white barytes, which, as shown by the cleavages, preserves its crystalline continuity over a considerable area. This barytes and some of the dolomite have crystallised around the tetrahedrite, and were the latest minerals to be formed; they present no natural faces, but only cleavage surfaces, through which the crystals of tetrahedrite project.

With the lens one or two minute crystals of what appeared to be copper-pyrites were observed on a crystal of tetrahedrite; but when the surface of the tetrahedrite crystals was illuminated with the aid of a Lieberkuhn

and examined under the microscope, minute yellow crystals were more often seen. The fractured surfaces of the tetrahedrite rarely showed a bright yellow tarnish due to a film of copper- or iron-pyrites.

Chemical Composition.—The result of the analysis was as follows (G. T. P.):—

			Atomic ratios.	
Cu	...	30·56	·4842	6
Ag	...	15·26	·1425	
Sb	...	27·73	·2320	2·21
As	...	trace		
Fe	...	3·51	·0631	·60
Zn	...	trace		
Pb	...	0·05	·0002	
S	.	23·15	·7272	6·96
		100·26		
Sp. gr.	...	5·047		

Weight used = 0·8911 gram, and 0·4447 gram for the sulphur determination. The atomic ratio of the total sulphur calculated for sulphides, on the assumption that iron is present as FeS, is ·7247. After deducting $3(Cu,Ag)_2S.Sb_2S_3$, the atomic ratios for the residual

$$Sb : (Fe,Zn) : S = ·21 : ·6 : ·97,$$

which correspond very closely to the formula $6(Fe,Zn)S.Sb_2S_3$. The combined formula is therefore the same as in the case of the Horhausen specimen:

$$[3(Cu,Ag)_2S.Sb_2S_3] + \tfrac{1}{10}[6(Fe,Zn)S.Sb_2S_3].$$

The above analysis resembles Rose's (see No. 2, p. 205) and the earlier analysis of Klaproth[1] of tetrahedrite from the Wenzel Mine, Wolfach, Baden.

(*e*) *Proposed new formula for Fahlerz (Tetrahedrite and Tennantite).*

$$3R'_2S.R'''_2S_3 + x[6R''S.R'''_2S_3],$$

where R′ = Cu,Ag; R″ = Fe,Zn; R‴ = Sb,As,Bi; and x is a small fraction, often = $\frac{1}{10}$ and $\frac{1}{5}$, but rising to $\frac{1}{2}$ in the case of the highly ferriferous tetrahedrite, "coppite."

The result of the analysis (p. 197) of the mineral from Dauphiné containing little iron or zinc served to substantiate the conclusion which had been arrived at from the analysis of binnite and the older analyses of tennantite and tetrahedrite of simple composition that the true formula for fahlerz proper is $3(Cu,Ag)_2S.(Sb,As)_2S_3$.

[1] *Beiträge*, 1807, IV, 71.

In the case of the last two analyses of specimens of less simple composition, if FeS and ZnS be taken as isomorphously replacing Cu_2S, the numbers obtained, like those of most analyses of tetrahedrite, correspond to a mixture of $3RS.Sb_2S_3$ and $4RS.Sb_2S_3$.

If, however, the above conclusion is accepted, that the true formula for the simple sulphantimonite of copper is $3Cu_2S.Sb_2S_3$, then the last two analyses serve to indicate in what way the iron and zinc enter into the composition of the more complex varieties of the mineral, for it is only necessary to deduct from the atomic ratios of the elements the whole of the Cu and Ag with part of the Sb,As and S to form $3(Cu,Ag)_2S.(Sb,As)_2S_3$, in order to see what ratio the (Fe,Zn) bears to the residual (Sb,As) and S.

As seen on pp. 200 and 202, application of this process to the last two analyses indicates that the Fe and Zn enter into the composition of the mineral as $6(Fe,Zn)S.Sb_2S_3$, the group 6(Fe,Zn)S and not 3(Fe,Zn)S isomorphously replacing $3Cu_2S$.

The new formula receives its theoretical explanation in the suggestion which is tentatively put forward that in the crystallisation of the normal sulphantimonite of copper, sulphides of iron and zinc in small amount may be drawn into the composition of the mineral in the form $(Fe,Zn)_6S_6.Sb_2S_3$, as the combination with sulphide of antimony most nearly approaching in structure to $Cu_6S_3.Sb_2S_3$. In fahlerz therefore $(Fe,Zn)_6S_6$ is supposed to isomorphously replace Cu_6S_3, owing to the predominating influence or "mass effect"[1] of the metallic atoms. The theory is thus an extension of the idea, which appears to be now gaining ground, that in many cases it is the number of atoms irrespective of their valency which is of importance in isomorphism[2] (*e.g.* the felspars $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$; calcite and sodium nitrate).

(*f*) *Test of the new formula by reference to the results of previous analyses.*

The following eighteen analyses on which to test the new formula are arranged in order of date, beginning with those of Rose,[3] from which the original 4 : 1 formula was deduced.

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[1] Compare Penfield, *Amer. Journ. Sci.* 1896, II, 8; Abstract *Min. Mag.* XI, 2'5. *Ibid.* 1899, VII, 123; Abstract this No. p. 217.

[2] Hamberg, *Geol. För. Förh.* 1890, XII, 598; Penfield and Foote, *Amer. Journ. Sci.* 1897, L, 110.

[3] Two out of Rose's seven analyses are not included, as they show intermixed matrix, and large percentages of both arsenic and antimony, the separation of which was by an imperfect method.

They are chosen for the most part as having been made on pure material and by good methods of analysis. As a rough test of the value of the analysis, in each case, to the atomic proportion of sulphur found is appended the atomic proportion of sulphur calculated to convert the other elements into sulphides (Cu_2S,FeS,Sb_2S_3 etc.).

After each analysis are given the atomic ratios of R″ (Fe,Zn), and of the residual R‴ (Sb,As,Bi) and S left after deducting the whole of the copper and silver and part of the R‴ and S to form $3(Cu,Ag)_2S.(Sb,As)_2S_3$. According to the new formula, in a perfect analysis the atomic ratios of R″ and the residual R‴ and S should be R″ : R‴ : S = 6 : 2 : 9.

In the cases where the colour of the streak is mentioned, the analyses will be seen to confirm the suggestion made on p. 192 that in fahlerz the black streak is due to the presence of iron in larger amount than 3 per cent.

(1). *Tetrahedrite from Zilla, near Clausthal, Harz.*

H. Rose (*Pogg. Ann.* 1829, XV, 578). Tetrahedral crystals with copper-pyrites and galena. Streak, very dark red.

				Atomic ratios.
Cu	...	34·48	·5468	6
Ag	...	4·97	·0464	
Sb	...	28·24	·2363	2+ ·392
Fe	...	2·27	·0408	1·278
Zn	...	5·55	·0855	
S	...	24·73	·7769 (Calc$^{d.}$ ·7771)	6+1·864
		100·24		

Residual R″ : R‴ : S = 1·278 : ·392 : 1·864
= 6·5 : 2 : 9·5

corresponding to $6RS.R_2S_3 + \cdot 5RS$.

Approx. formula : $[3R_2S.Sb_2S_3] + \frac{1}{5}[6RS.Sb_2S_3]$.

(2). *Tetrahedrite from Wenzel Mine, Wolfach, Baden.*

Rose (*loc. cit.* p. 579). Crystals with barytes and galena on talcose gneiss. Streak, black

				Atomic ratios.
Cu	...	25·28	·3997	6
Ag	...	17·71	·1653	
Sb	...	26·63	·2228	2+ ·365
Fe	...	3·72	·0669	1·217
Zn	...	3·10	·0478	
S	...	23·52	·7389 (Calcd. ·7314)	6+1·844
		99·91		

Residual R″ : R‴ : S = 1·217 : ·365 : 1·844
= 6·6 : 2 : 10

corresponding to $6RS.R_2S_3 + \cdot 5RS_2$.

Approx. formula : $[3R_2S.Sb_2S_3] + \frac{1}{5}[6RS.Sb_2S_3]$.

(3). *Tetrahedrite from Dillenburg, Nassau.*

Rose (*loc. cit.* p. 578). Tetrahedral crystals with copper-pyrites. Streak, cherry-red.

				Atomic ratios.
Cu	...	38·42	·6087	6
Ag	...	0·83	·0077	
Sb	...	25·27	·2115	2+ ·355
As	...	2·26	·0304	
Fe	...	1·52	·0273	1·292
Zn	...	6·85	·1055	
S	...	25·03	·7864 (Calcd ·8038)	6+1·655
		100·18		

Residual R″ : R‴ : S = 1·292 : 355 : 1·655
= 7 : 2 : 9

corresponding to $6RS.R_2S_3 + R''$.

Approx. formula : $[3R_2S.R_2S_3] + \frac{1}{6}[6RS.R_2S_3]$.

(4). *Tetrahedrite from Kapnik, Hungary.*

Rose (*loc. cit.* p. 577). Crystals with quartz, galena, iron-pyrites and blende. Streak, dark red.

				Atomic ratios.
Cu	...	37·98	·6017	6
Ag	...	0·62	·0058	
Sb	...	23·94	·2003	2+ ·361
As	...	2·88	·0387	
Fe	...	0·86	·0155	1·262
Zn	...	7·29	·1123	
S	...	25·77	·8096 (Calcd. ·7901)	6+1·996
		99·34		

Residual R″ : R‴ : S = 1·262 : ·361 : 1·996
= 6·7 : 2 : 10·7

corresponding to $6RS.R_2S_3 + \cdot 7RS_2$.

Approx. formula: $[3R_2S.R_2S_3] + \frac{1}{6}[6RS.R_2S_3]$.

(5). *Argentiferous Tetrahedrite from Freiberg, Saxony.*

Rose (*loc. cit.* p. 579). Tetrahedral crystals with galena, copper-pyrites, red-silver, blende and quartz. Streak, black.

				Atomic ratios.
Cu	...	14·81	·2346	6
Ag	...	31·29	·2921	
Sb	..	24·63	·2061	2+ ·348
Fe	...	5·98	·1076	1·285
Zn	...	0·99	·0152	
S	...	21·17	·6651 (Calcd. ·6852)	6+1·577
		98·87		

Residual R″ : R‴ : S = 1·285 : ·348 : 1·577
= 7 : 2 : 9

corresponding to $6RS.Sb_2S_3 + R''$.

Approx. formula: $[3R_2S.Sb_2S_3] + \frac{1}{6}[6RS.Sb_2S_3]$.

(6). *Tetrahedrite from Clausthal, Harz.*

Schindling (*Neues Jahrb. f. Min.* 1856, 335). Tetrahedral crystals, coated with copper-pyrites.

				Atomic ratios.
Cu	...	33·145	·5251	6
Ag	...	5·135	·0479	
Sb	...	28·520	·2387	2+ ·499
Fe	...	2·780	·0491	1·446
Zn	...	5·775	·0890	
S	...	25·655	·8060 (Calcd. ·7826)	6+2·446
		100·960		

Residual R'' : R''' : S = 1·446 : ·499 : 2·446
= 5·8 : 2 : 9·8

corresponding to $6RS.Sb_2S_3 + \cdot 8S$.

Approx. formula: $[3R_2S.Sb_2S_3] + \frac{1}{2}[6RS.Sb_2S_3]$.

(7). *"Coppite" from Val di Frigido, Tuscany.*

Bechi (D'Achiardi *Min. Tosc.* 1873, II, 341, from *Cont. Atti Accad. Georgofili, Florence*, 1868, X, 203). Compact and homogeneous. Sp. gr. 4·713.

				Atomic ratios.
Cu	...	30·10	·4769	6
Sb	...	29·61	·2478	2+1·116
Fe	...	13·08	·2352	2·959
S	...	27·01	·8486 (Calcd. ·8453)	6+4·674
		99·80		

Residual R'' : R''' : S = 2·959 : 1·116 : 4·674
= 5·3 : 2 : 8·4

corresponding to $6FeS.Sb_2S_3 - \cdot 6RS$.

Approx. formula: $[3Cu_2S.Sb_2S_3] + \frac{1}{2}[6FeS.Sb_2S_3]$.

(8). *Mercurial Tetrahedrite from Moschellandsberg, Rhenish Bavaria.*

Oellacher (Sandberger, *Neues Jahrb. f. Min.* 1865, 596). Crystals with copper-pyrites. Streak, black. Sp. gr. 5·095.

				Atomic ratios.
Cu	...	32·19	·5100	6
Sb	...	23·45	·1962	2+ ·446
As	...	0·31	·0041	
Bi	...	1·57	·0076	
Fe	...	1·41	·0254	1·390
Zn	...	0·10	·0015	
Hg	...	17·32	·0873	
Co	...	0·23	·0040	
S	...	21·90	·6880 (Calcd ·6819)	6+2·095
Gangue	...	1·39		
		99·87		

Residual R'' : R''' : S = 1·390 : ·446 : 2·095
= 6·2 : 2 : 9

corresponding to $6RS.R_2S_3$.

Approx. formula: $[3Cu_2S.R_2S_3] + \frac{1}{4}[6RS.R_2S_3]$.

(9). *Tetrahedrite from De Soto Mine, Star City, Nevada.*

Burton (*Amer. Journ. Sci.* 1868, XLV, 37). Massive, with blende and pyrites. Sp. gr. 5·00.

				Atomic ratios.
Cu	...	27·40	·4340	6
Ag	...	14·59	·1362	
Sb	...	27·35	·2289	2+ ·408
Fe	...	4·27	·0768	1·183
Zn	...	2·31	·0356	
S	..	24·35	·7650 (Calcd ·7409)	6+2·049
Insol.	...	0·35		
		100·62		

Residual R'' : R''' : S = 1·183 : ·408 : 2·049
= 6 : 2 : 10

corresponding to $6RS.R_2S_3+S$.

Approx. formula: $[3R_2S.Sb_2S_3] + \frac{1}{5}[6RS.Sb_2S_3]$.

(10). *"Julianite" from Rudelstadt, Silesia.*

Websky (*Zeits. Deutsch. geol. Ges.* 1871, XXIII, 486). Small cubo-dodecahedra in calcite. Sp. gr. 5·12.

				Atomic ratios.
Cu	...	52·298	·8286	6
Ag	..	0·538	·0050	
Sb	...	1·421	·0118	1·708
As	...	16·782	·2255	
Fe	...	0·787	·0142	·102
S	...	26·503	·8326 (Calc$^{d.}$ ·7870)	5·993
		98·329		

The numbers correspond approximately to $3Cu_2S.As_2S_3$. The correspondence is more exact if, as is most probable from the imperfect method of analysis (fusion with nitre and sodium carbonate), the loss in the analysis is due to loss of arsenic.

This analysis is given as one of the few made on material of comparatively simple composition.

(11). *"Aphthonite" from Gärdsjö, Wermland, Sweden.*

Nilson (*Zeits. Kryst. Min.* 1877, I, 417). Massive, with small veins of copper-pyrites. Streak, dark brownish red.

				Atomic ratios.
Cu	...	41·06	·6505	6
Ag	...	6·16	·0575	
Sb	...	26·85	·2247	1·904
Fe	...	0·95	·0171	·152
Zn	...	0·71	·0109	
S	...	23·56	·7462 (Calc$^{d.}$ ·7090)	6·27
		99·29		

The numbers correspond very closely with the formula $3Cu_2S.Sb_2S_3$.

(12). *Fahlerz from Kahl, near Bieber, in Hesse.*

Mutschler (Sandberger, *Neues Jahrb. f. Min.* 1877, 275). Sp. gr. 4·75.

				Atomic ratios.
Cu	...	36·3	·5751	6
Ag	...	0·5	·0050	
Sb	...	24·9	·2084	2+ ·516
As	...	2·6	·0349	
Fe	...	3·6	·0648	1·475
Zn	...	4·5	·0693	
Co	...	0·5	·0085	
S	...	25·9	·8137 (Calcd. ·7974)	6+2·415
		98·8		

Residual R″ : R‴ : S = 1·475 : ·516 : 2·415
= 5·7 : 2 : 9·3

corresponding to $6RS.R_2S_3$.

Approx. formula: $[3R_2S.R_2S_3] + \frac{1}{4}[6RS.R_2S_3]$.

(13). *Fahlerz from Huallanca, Peru.*

Comstock (*Amer. J. Sci.* 1879, XVII, 401). Large tetrahedral crystals. Sp. gr. 4·7.

				Atomic ratios.
Cu	...	39·09	·6193	6
Ag	...	3·86	·0360	
Sb	...	9·06	·0758	2+ ·354
As	...	13·49	·1812	
Fe	...	5·46	·0982	1·201
Zn	...	2·14	·0330	
S	...	26·74	·8401 (Calcd. ·8453)	6+1·693
		99·84		

Residual R″ : R‴ : S = 1·201 : ·354 : 1·693
= 6·7 : 2 : 9·6

corresponding to $6RS.Sb_2S_3 + \cdot 6RS$.

Approx. formula: $[3R_2S.R_2S_3] + \frac{1}{5}[6RS.R_2S_3]$.

(14). *Fahlerz from Kapnik, Hungary.*

Hidegh (*Tsch. Min. Mitth.* 1879, II, 350—8). Crystals with blende. Sp. gr. 4·91 (compare No. 4 above).

			Atomic ratios.	
Cu	...	37·83	·5993	6
Ag	...	1·32	·0123	
Sb	...	24·21	·2026	2+ ·423
As	...	2·88	·0444	
Fe	...	0·94	·0169	1·262
Zn	...	7·25	·1117	
S	...	25·31	·7951 (Calcd. ·8049)	6+1·801
		99·74		

Residual R'' : R''' : S = 1·262 : ·423 : 1·801
= 6 : 2 : 8·5

corresponding to $6RS.R_2S_3$.

Approx. formula: $[3R_2S.R_2S_3] + \frac{1}{5}[6RS.R_2S_3]$.

(15). *Tennantite from Szászka, Hungary.*

Hidegh *(loc. cit.)*. Dodecahedral crystals associated with redruthite. Sp. gr. 4·92.

			Atomic ratios.		
Cu	...	53·60	·8491	6	7
Ag	...	0·08	·0008		
Sb	...	0·10	·0008	1·736	2
As	...	19·11	·2567		
Fe	...	0·39	·0070	·05	
S	...	25·98	·8162 (Calcd. ·8181)	5·76	6·5
		99·26			

Approx. formula: $3Cu_2S.As_2S_3 + \frac{1}{2}Cu_2S$ (redruthite).

(16). *Fahlerz from Herrengrund, Hungary.*

Hidegh *(loc. cit.)* Imperfect crystals, somewhat altered. Sp. gr. 4·77.

			Atomic ratios.	
Cu	...	39·81	·6307	6
Ag	...	0·05	·0005	
Sb	...	22·82	·1909	2+ ·421
As	...	4·75	·0638	
Fe	...	4·75	·0854	1·023
Zn	...	1·44	·0222	
S	...	25·75	·8090 (Calcd. ·8052)	6+1·690
		99·87		

Residual R'' : R''' : S = 1·023 : ·421 : 1·690
= 5 : 2 : 8

corresponding to $6RS.R_2S_3 - RS$.

Approx. formula: $[3Cu_2S.R_2S_3] + \frac{1}{5}[6RS.R_2S_3]$.

(17). *Tennantite from Mollie Gibson Mine, Aspen, Colorado.*

Penfield (*Amer. Journ. Sci.* 1892, XLIV, 18). Massive; intermixed with polybasite, from which it only slightly differs in colour. Sp. gr. 4·56.

			Atomic ratios.	
Cu	...	35·72	·5659	6
Ag	...	13·65	·1274	
Sb	...	0·13	·0011	2·007
As	..	17·18	·2308	
Fe	...	0·42	·0075	·985
Zn	...	6·90	·1063	
Pb	...	0·86	·0042	·036
S	...	25·04	·7867 (Calcd. ·8125)	6·808
		99·90		

This analysis is introduced as being one of the very few which agree closely with the 4 : 1 formula, in this case $3Cu_2S.ZnS.Sb_2S_3$. The result of the analysis can only be made to agree with the new 3 : 1 formula, either by supposing the zinc to be present as blende, or, as is more probable from the mode of occurrence of the mineral, by supposing that

the material analysed contained admixed polybasite, as shown in the following formula :—

$$9\,[3Cu_2S.As_2S_3] + 2\,[6ZnS.As_2S_3] + [9(Ag,Cu)_2S.As_2S_3].$$

Tennantite. Polybasite.

Taking the atomic proportion of copper and silver in the polybasite to be 1 : 3, as given by Penfield's analysis *(loc. cit.)*, the atomic proportion of these elements in the above formula is about 9 : 2, which is in fairly close agreement with the results of the analysis.

(18). *Fahlerz from Clausthal, Harz.*

Fraatz (W. Hampe, *Chem.-Zeit.* 1893, XVII, p. 1691). Crystals coated with copper-pyrites, but the selected material appeared to be perfectly homogeneous under the microscope. The mean of two closely agreeing analyses is—

			Atomic ratios.	
Cu	...	35·645	·5642	6
Ag	...	3·365	·0314	
Sb	...	28·63	·2394	2+ ·412
Fe	...	2·36	·0422	1·247
Zn	...	5·29	·0815	
S	...	24·72	·7725 (Calcd. ·7806)	6+1·7826
		100·01		

Residual R'' : Sb : S = 1·247 : ·412 : 1·782
= 6 : 2 : 8·65

corresponding to $6RS.Sb_2S_3$.

Approx. formula : $[3R_2S.Sb_2S_3] + \frac{1}{6}[6RS.Sb_2S_3]$.

In support of the new formula particular attention may be drawn to the analyses of Rose (Nos. 1-5), to the analysis of "coppite" (No. 7) in which the percentage of iron is as high as 13, and to the analysis of Fraatz (No. 18) which is one of the most recent analyses of tetrahedrite made on pure crystallised material.

REVIEW.

The Characters of Crystals, an Introduction to Physical Crystallography. By Alfred J. Moses, E.M., Ph.D., Professor of Mineralogy, Columbia University, New York City. Pp. 211 + VIII. with 321 Text figures. (New York : D. van Nostrand Company, 1899).

Professor Moses has reprinted the series of papers which appeared during the past two years in the *School of Mines Quarterly*, and presents us with an elementary treatise on the physical questions connected with crystals, which will undoubtedly be found most useful by every mineralogical student. In a small compass he gives a very clear sketch of the apparatus and methods used in crystallography without employing any but the simplest mathematics, and thus makes it intelligible to students whose attainments in this subject are not of a high order. In many cases—notably in the chapters dealing with the optical phenomena—the proofs have been omitted altogether, and the reader is referred to other works for fuller and more detailed information.

The book is divided into three parts, dealing respectively with the geometrical, the optical and, finally, the remaining physical characters of crystals. The author follows Groth in avoiding all ideas of hemihedrism, and introduces a simple and effective nomenclature. On this point may we venture to hope that teachers of mineralogy will ere long come to some agreement in the names adopted for the thirty-two classes of symmetry? To explain the phenomena connected with the transmission of light through a crystalline medium, Professor Moses employs Fletcher's geometrical treatment, which avoids all questions as to the properties of the luminiferous aether. In the third part scarcely enough prominence seems to be given to the importance of etching in determining the crystalline symmetry, as exemplified by the researches of Baumhauer and Beckenkamp. In an appendix is added the very complete graduate course in Physical Crystallography given in Columbia University.

The book is well printed on good paper, and enhanced in value by numerous excellent figures.

ABSTRACTS.

Chapters on the Mineralogy of Scotland. Chapter VIII, Silicates. (M. F. Heddle, *Trans. Roy. Soc. Edin.* 1899, XXXIX, 341-359.)—Previous "chapters" of this series have been noticed in vols. II, III and IV of this Magazine. The present paper gives a collection of 19 analyses of andalusite, tourmaline, fibrolite, kyanite, epidote, zoisite and idocrase from Scottish localities. Several of these analyses were published in the early volumes of the Magazine in the author's papers on "The County Geognosy and Mineralogy of Scotland." L. J. S.

Baddeleyite from Alnö, Sweden. (E. Hussak, *Neues Jahrb. Min.* 1898, II, 228-9.)—Baddeleyite (ZrO_2), previously only known from Ceylon and Brazil, is now recorded as an accessory constituent in a basic separation from the nepheline-syenite of Alnö, Sweden. This rock, consisting of olivine, magnetite and calcite, corresponds to the basic mother-rock (jacupirangite) of baddeleyite in the nepheline-syenite district of Brazil. From 100 grams of the Swedish rock 0·38 gram of baddeleyite crystals was isolated. They are about $1-1\frac{1}{2}$ mm. across, and of a dark chestnut-brown colour; in angles and twinning they agree with the previous descriptions (*Min. Mag.* X, 148; XI, 110), the only difference being in the stronger pleochroism. L. J. S.

Crystals in Blowpipe Beads. (W. Florence, *Neues Jahrb. Min.* 1898, II, 102-146).—A systematic account is given of the results obtained on heating various substances in borax and sodium phosphate beads with or without lead oxide. Numerous figures are given of the crystals characteristic for each element so treated. The method is recommended for the microscopical determination of minerals in the dry way. L. J. S.

Optical Properties of Zoisite (P. Termier, *Bull. Soc. fran. Min.* 1898, XXI, 148-170).—Small crystals of zoisite from a mica-schist at Bobbio in the Cottian Alps have the optic axial plane approximately parallel to $c(001)$, and the acute positive bisectrix nearly normal to $a(100)$; $\rho > v$, $2V = 35° - 40°$, $\alpha = \beta = 1{\cdot}696$, $\gamma = 1{\cdot}703$. Analysis gives the usual zoisite formula $HCa_2(Al,Fe)_3Si_3O_{13}$, with $Al : Fe = 9 : 1$; sp. gr. $= 3{\cdot}36$. Zoisite from Vanoise in the Savoy Alps has the same optical characters, and both are distinguished as β-zoisite.

The zoisite first examined by Des Cloizeaux differs optically from these, and is called α-zoisite. Here the acute positive bisectrix has the same position as before, but the optic axial plane is approximately parallel to the perfect cleavage $b(010)$; also the dispersion $\rho < \upsilon$ is much greater, and sections parallel to $a(100)$ do not completely extinguish, but are coloured violet between crossed nicols in white light. Zoisite from Ducktown in Tennessee, North Carolina, Sau Alpe, and other localities, consists of a regular intergrowth of these two optical varieties, which are identical in chemical composition and crystalline form, being probably anorthic with very nearly rectangular axes. L. J. S.

Chemical Composition of Tourmaline. (S. L. Penfield and H. W. Foote, *Amer. J. Sci.* 1899 [iv], VII, 97-125; and *Zeits. Kryst. Min.* 1899, XXXI, 321).—A detailed historical review is given of the several formulæ which have been proposed for this complex boro-silicate. So many analyses have previously been made that, in order to establish a formula, it was thought best to make two accurate analyses on very carefully selected material of different types. Analysis I is of clear, colourless, glassy, and perfectly pure tourmaline from De Kalb, St. Lawrence Co., New York; sp. gr. > 3·003 < 3·065. Anal. II is of small transparent prisms of a uniform pale green colour from Haddam Neck on the Connecticut River: sp. gr. = 3·089.

	SiO_2.	TiO_2.	B_2O_3.	Al_2O_3.	FeO.	MnO.	MgO.	CaO.	Na_2O.	K_2O.	Li_2O.	H_2O.	F.	Total less O for F.
I,	36·72	0·05	10·81	29·68	0·22	—	14·92	3·45	1·26	0·05	—	2·98	0·93	100·72
II,	36·96	0·03	11·00	39·56	2·14	2·00	0·15	1·28	2·10	—	1·64	3·10	1·13	100·61

These do not give any simple molecular ratios, but by taking the number of hydrogen atoms equivalent to the different metals (*e.g.* Al_2O_3 replaced by 6H) the ratios become, for I, $SiO_2 : B_2O_3 : H = 4 : 1 : 19{\cdot}90$, and for II, $= 4 : 1{\cdot}02 : 19{\cdot}98$. The tourmaline acid is therefore $H_{20}B_2Si_4O_{21}$. Previous analyses are discussed in detail, and made to agree with this formula when the necessary corrections are introduced. For example, in Rammelsberg's thirty analyses the determinations of the silica were probably too high and for the water too low.

The ratio SiO_2 : (OH,F) is not constant, but in all analyses the water when directly determined, is enough for 2(OH), and in only a few cases enough for 3(OH). Further aluminium is always present in sufficient amount to replace more than half the hydrogen atoms. All varieties of tourmaline may therefore be considered as salts of the aluminium boro-silicic acid $H_9Al_3(B.OH)_2Si_4O_{19}$. The remaining 9H may be replaced by

aluminium, alkalies, magnesium and iron in varying proportions, and there may also be some basic hydrogen. For example, in the Haddam Neck tourmaline (Anal. II), 6·1H is replaced by Al, 1·1H by R″, 1·2H by R′, whilst 0·6 is basic hydrogen.

When arranged according to the amount of aluminium present, tourmalines fall into the following groups: (1) Lithia tourmaline, with much Al and little Mg and Fe; these are generally light-coloured and transparent, and difficultly fusible, and are found in pegmatite veins. (2) Iron tourmalines. (3) Magnesia-iron tourmalines. The last two varieties are black or dark brown, owing to the presence of iron, and occur in granite, gneiss and schist, though sometimes also in pegmatite veins. (4) Magnesia tourmalines with the least amount of Al; these are light-coloured and easily fusible, and occur in crystalline contact limestones.

These different varieties are the same in crystalline form, and are isomorphous because of the mass effect of the complex radicle $[Al_3(B.OH)_2Si_4O_{19}]$, which is so great that alkalis, R″ and aluminium must be considered as isomorphous constituents, just as sodium (Na_2) and calcium are isomorphous in the complex zeolites and in the sodalite-garnet group, although they are not isomorphous in more simple compounds.

L. J. S.

Sulphur and other minerals from the Malfidano Mine near Buggern, Sardinia. (Dr. F. Miltosevich, *Atti R. Acc. dei Lincei*, V. 249, 1898.)—Some small crystals, rich in faces, were found with anglesite in galena. The forms observed are $a(100)$, $b(010)$, $c(001)$, $m(110)$, $n(011)$, $v(013)$, $e(101)$, $u(103)$, $\phi(305)$, $p(111)$, $\psi(119)$, $w(117)$, $t(115)$, $o(114)$, $s(113)$, $y(112)$, $\delta(221)$, $\gamma(331)$, $\chi(122)$, $q(131)$, $x(133)$, $z(135)$, $\lambda(155)$, $r(311)$, $\alpha(313)$, $\beta(315)$, $\mu(319)$, of which ϕ, λ and μ are new. The most prominent forms are p, s, y, q, β and α The crystals are very similar to those from Saba, East Indies, described by Molengraaff (*Zeits. Kryst. Min.* XIV. 1888, 43). The axial ratios are $a : b : c = 0{\cdot}81368 : 1 : 1{\cdot}90472$, very near those determined by Koksharov.

Together with those of sulphur are numerous crystals of anglesite. The crystals are tabular parallel to (001), and have the forms $a(100)$, $c(001)$, $m(110)$, $n(120)$, $o(011)$, $d(102)$, $z(111)$, $y(122)$. There are also a few thin laminar crystals of barytes, with the forms $c(001)$, $m(110)$, $o(011)$, and $z(111)$.

G. F. H. S.

Papers on the Symmetry of Crystals, 1888-1898. (J. Beckenkamp.)

The Minerals of the Aragonite Group. (J. Beckenkamp, *Zeits. Kryst. Min.* 1888, XIV, 376-385.)—The minerals aragonite, strontianite, witherite and cerussite are so closely allied in their chemical composition, their geometrical form and physical characters, that they may undoubtedly be considered to have the same arrangement of atoms and molecules. In this paper the author confines himself mainly to crystals of aragonite from Bilin. Except in the case of strontianite from Oberschaffhausen, previously described by him, no trace of hemihedrism has been found in this group. The striations on faces of the form (110) on Bilin crystals indicate that the *c*-axis is polar, which is confirmed by Hankel's investigations on the thermoelectric characters of aragonite. But the most interesting results follow from considering the figures produced by etching sections parallel to (001) with a 20 per cent. solution of HCl for about a minute. The crystals are clearly shown to be composed of different individuals. The Bilin crystals are twinned about (010) as well as about (110). Each individual is hemimorphic with regard to *b* and *c*; *a*, the only axis of symmetry, is polar, and there are no planes of symmetry. This arrangement agrees with the system of striations on the Bilin aragonite and also with the geometrical form of the Oberschaffhausen strontianite, if considered as twinned about (001). The author then explains this type of crystal growth on the hypothesis that during crystallisation heat is emitted which gives rise to electric currents.

1. *Previous observations and deductions therefrom.* (*Zeits. Kryst. Min.* 1890, XVII, 321 330.)—The main conclusions the author draws from his own work and that of other observers (chiefly Hankel[1] and Lehmann[2]) are as follows :—

(*a*) The anomalies found in crystals of barytes and strontianite can only be explained by regarding the crystals as composed of individuals of very low symmetry.

(*b*) There is no important difference between crystals with an apparently symmetrical electrical axis and those with a one-sided axis.

(*c*) The electrical stresses arising during the growth of a crystal have a most important influence on the arrangement of the molecules.

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[1] *Elektrische Untersuchungen*, 9te Abhandlung, 1872. [2] *Molekularphysik*, 1889.

(*d*) Holohedral and holomorphic crystals are impossible, and can only owe their apparent existence to twinning.

2. *Gypsum from Zimmersheim in Upper Alsace.* (*Ibid.* 1890, XVII, 331-335.)—Imbedded in fibrous gypsum were found crystals of the same mineral, varying in length up to 10 mm. Microscopic investigation showed that the direction of the fibres always coincided with the *c* prism edge. The crystals display striation-zones, the direction of which coincides with that of the fibres. These striations might be supposed to be due to the pressure of the fibres on the completed crystals; but, since the angles between the faces show no greater variation than is found in the case of crystals which have grown freely, and, moreover, since there is no trace of further disturbance, the author thinks it more probable that these striations arose during the growth of the crystals. Three crystals were measured, and the position of the striation-zone determined in each case. The forms present are (010), (11$\bar{1}$), (111) and (110). The pyramid faces which lie nearest to the striation-zone are invariably the largest. The striation-zones have never quite the same crystallographic orientation. The author finally concludes that the mutual attractions of the molecules is independent of the surrounding conditions, but dependent on the direction in the crystal, and also that a crystal face has at least two directions of maximum attraction.

3. *Aragonite from Bilin.* (*Ibid.* 1891, XIX, 242-264, and 1892, XX, 161-163.)—A careful examination was made of the vicinal faces, and their positions determined as accurately as possible. The axial ratios calculated from the angles between faces of the form (121) are $a:b:c=0{\cdot}62280:1:0{\cdot}72036$. The symmetry derived from the vicinal faces was not in accordance with that derived from a study of the etched figures (see above, *The Minerals of the Aragonite Group*). Further experiments, especially those of von Ebner, in which formic acid was the agent employed, show that the symmetry is the same in both cases. The author finally concludes that the three axes are enantiopolar directions, and the principal planes are planes of twinning; also the simple crystal has rhombic ogdohedral symmetry. The author accounts for the vicinal faces on the theory that the electrical attraction is tangential and not normal to a crystal face, as has been generally supposed.

4. *Calcite from Nieder-Rabenstein.* (*Ibid.* 1892, XX, 163-167.)—The crystals observed are of two types: scalenohedral and prismatic. The most prominent form on crystals of the first type is 20$\bar{1}$. It usually has smooth faces. The ends are terminated by (610), which is striated

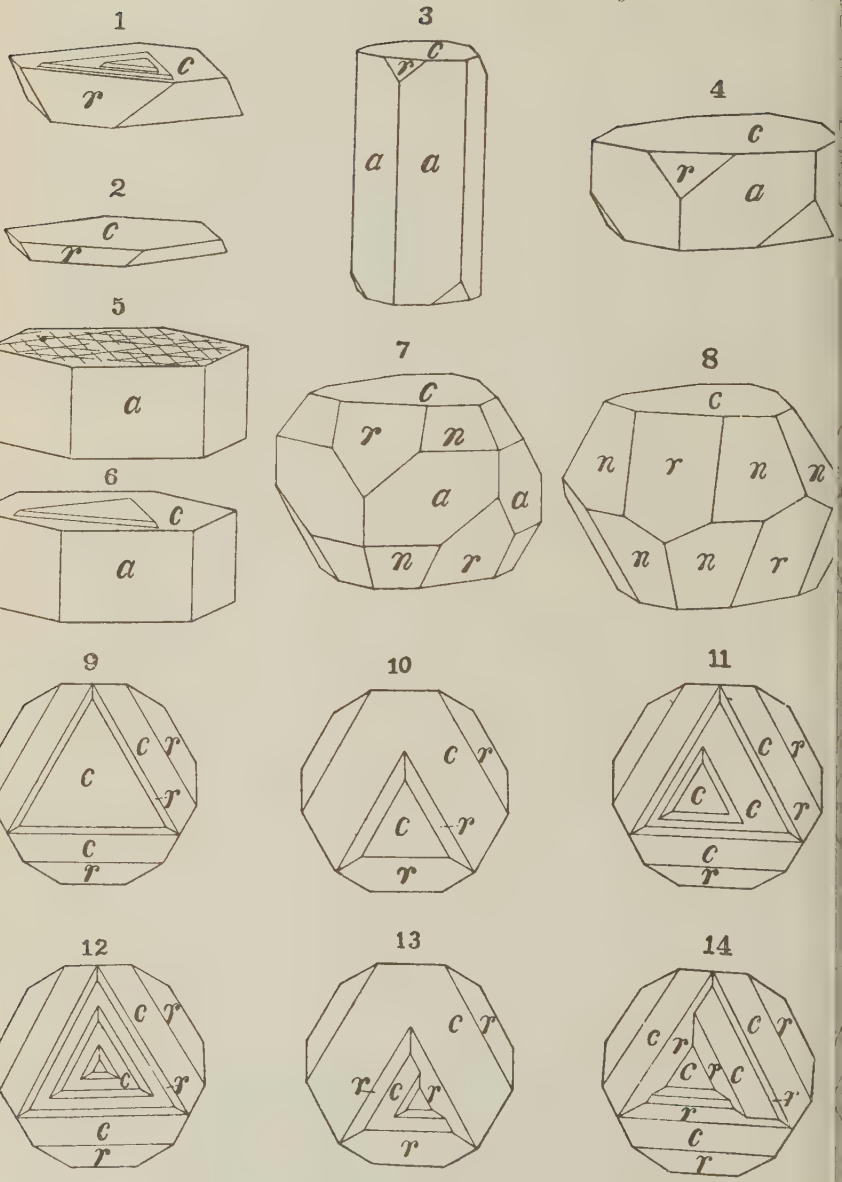
parallel to its acute edge, and also by (110). The majority of the crystals are traversed by lamellæ twinned about (110), which gives them a monosymmetric character. Should the distance between alternate layers be the molecular thickness, then these crystals must both geometrically and physically belong to the monosymmetric system The crystals of the second type are distinguished by the predominance of the prism of the first order, or a form very near it. There also appear $(3\bar{1}\bar{1})$ and $(11\bar{1})$ and sometimes a form near $35\cdot\bar{1}9\cdot\bar{1}3]$. From striations and the difference of the sizes to which faces of the form $(20\bar{1})$ have developed, the author concludes that crystals of this type have tetartohedral-hemimorphic or ogdohedral symmetry. Since Kobell and Tschermak have shown that dolomite belongs to this type of symmetry, the question arises whether the crystals are not really dolomite. But chemical, geometrical and physical tests showed clearly that they are calcite.

5. *Barytes.* (*Ibid.* 1897, XXVII, 583-585; 1897, XXVIII, 69-102; 1897, XXX, 55-65.)—Hemimorphic crystals have been described previously by the author and others. He here describes twins about (2.1.128) and (0.300.1). Barytes cannot then belong to the holohedral rhombic class of symmetry.

In the second paper the vicinal faces and pyroelectrical and etching experiments are described and discussed at length. The axial ratios calculated from the angles $(110):(1\bar{1}0)$ and $(011):(01\bar{1})$ are $a:b:c=0{\cdot}8146:1:1{\cdot}3119$. Two kinds of habit were noticed: crystals elongated in the direction of the macro- or brachy-diagonal. The symmetry of both is the same. A completely developed crystal of barytes is composed of eight individuals symmetrically disposed with respect to the three pinacoids. The molecule must have electrical polarity, on which depends the growth of the crystal and also its decay when acted on by solvents. The author then gives a mechanical explanation of pyroelectrical phenomena in barytes. In the third paper he discusses the possible molecular arrangement, and coucludes that it must consist of a double network of similar molecules, the corner of each network being at the centre of the other.

6. *Twins with inclined axes.* (*Ibid.* 1898, XXX, 321-325.)—Each molecule may be supposed to have three circular currents flowing round it in planes mutually perpendicular. Equilibrium will be established when corresponding planes of adjacent molecules are parallel, and also when they are inclined. The author uses this theory to explain the twinning and growth of aragonite and tridymite.

7. *The Rotation of the Plane of Polarisation.* (*Ibid.* 1898, XXX, 325-345; Cf. *Ann. Phys. Chem.* 1899, LXVII, 474-480.)—A short critical account of the history of the subject is first given, and the statical theories of Mallard and Sohncke studied in detail. These depend on an arrangement of monoclinic or triclinic sections similar to that of mica in Reusch's experiment. They fail, however, to account for the fact that equally thick plates of optically active crystals of the cubic system have the property of rotating the plane of polarisation an equal amount independently of the orientation in the crystal. Using the structural arrangement for quartz and tridymite given in the preceding paper, the author shows how the optical activity and inactivity may be explained in the two cases. Further, he shows that in the case of a cubic or octahedral network the rotation depends on the thickness of the plate, and not on its orientation in the crystal. G. F. H. S.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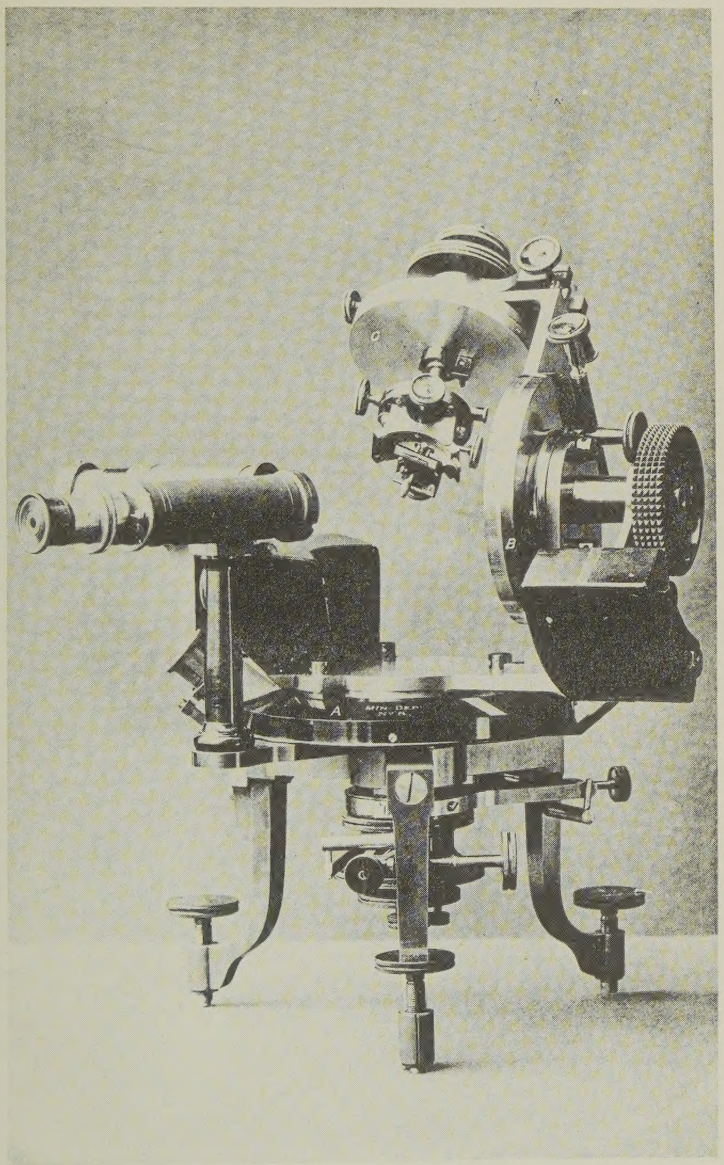
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